Total Maximum Daily Load for Sediment/Siltation and Organic Enrichment/Low Dissolved Oxygen

Bee Lake

Holmes County, Mississippi

[FINAL Report – SEPTEMBER 2003]

Prepared for:

Mississippi Department of Environmental Quality
Office of Pollution Control
TMDL/WLA Section/Water Quality Assessment Branch

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FOREWORD

This report has been prepared in accordance with the schedule contained within the federal consent decree dated December 22, 1998. The report contains two Total Maximum Daily Loads (TMDLs) for water body segments found on Mississippi's 1996 Section 303(d) List of Impaired Water bodies. Because of the accelerated schedule required by the consent decree, many of these TMDLs have been prepared out of sequence with the State's rotating basin approach. The implementation of the TMDLs contained herein will be prioritized within Mississippi's rotating basin approach.

The amount and quality of the data on which this report is based are limited. As additional information becomes available, the TMDLs may be updated. Such additional information may include water quality and quantity data, changes in pollutant loadings, or changes in land use within the watershed. In some cases, additional water quality data may indicate that no impairment exists.

Prefixes for Fractions and Multiples of SI Units

Fraction	Prefix	Symbol	Multiple	Prefix	Symbol
10^{-1}	deci	D	10	deka	da
10^{-2}	centi	C	10^{2}	hecto	h
10^{-3}	milli	M	10^{3}	kilo	k
10^{-6}	micro	µ	10^{6}	mega	M
10^{-9}	nano	N	10^{9}	giga	G
10^{-12}	pico	P	10^{12}	tera	T
10^{-15}	femto	F	10^{15}	peta	P
10^{-18}	atto	A	10^{18}	exa	E

Conversion Factors

TO CONVERT FROM	**To**	**Multiply by**	TO CONVERT FROM	**To**	**Multiply by**
Acres	Sq. miles	0.0015625	Days	Seconds	86400
Cubic feet	Cu meter	0.028316847	Feet	Meters	0.3048
Cubic feet	Gallons	7.4805195	Gallons	Cu feet	0.133680555
Cubic feet	Liters	28.316847	Hectares	Acres	2.4710538
Cubic feet per second	Gallions per minute	448.83117	Miles	Meters	1609.344
Cubic feet per second	Million gallions per day	0.6463168	Milligrams per liter	Parts per million	1
Cubic meters	Gallons	264.17205	Micrograms per liter times cubic feet per second	Grams per day	2.45

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TMDL Summary

Total Maximum Daily Load (TMDL) for Sediment/Siltation, Nutrients, and Organic Enrichment/Low Dissolved Oxygen (DO) in Bee Lake MS361BLM1, Holmes, Mississippi

TMDL AT A GLANCE

State:	Mississippi
County:	Holmes County
303(d) Listed Water body:	Yes
Year Listed:	1996
303 (d) List Segment ID:	MS361BLM1 – Bee Lake
HUC:	08030206 – Yazoo River Basin
Constituents Causing Impairment:	Siltation, nutrients, and organic enrichment
Source of Pollutants:	Agriculture, Aquaculture, and Natural Background
Data Source:	Clean Lake Assessments
Designated Uses:	Aquatic Life Support
Applicable Water Quality Standard:	*Sediment*: Narrative water quality criteria *Organic Enrichment/Low DO:* General water quality criteria for dissolved oxygen: a daily average of 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L.
Water Quality Target:	*Sedimentation/Siltation*: Average annual sediment sedimentation rate of 0.07 cm/year or 0.04 cm/year *Organic Enrichment/Low DO:* Daily Average DO of 5.0 mg/L
Technical Approach:	*Sedimentation/Siltation:* GWLF watershed model *Organic Enrichment/Low DO:* CE-QUAL-W2 receiving water model
TMDL:	*Sedimentation/Siltation:* 0.33 : 0.20 tons/acre/year *Organic Enrichment/Low DO:* 234 lbs/day of TBODu
WLA:	*Sedimentation/Siltation:* 0.33 :0.20 tons/acre/year *Organic Enrichment/Low DO:* 0 lbs/day of TBODu
LA:	*Sedimentation/Siltation:* 0.33 : 0.20 tons/acre/year *Organic Enrichment/Low DO:*234 lbs/day of TBODu
Margin of Safety:	Implicit

Executive Summary

Bee Lake, located in Holmes County, Mississippi, is an oxbow lake formed by an abandoned meander of the Yazoo River. The Mississippi Department of Environmental Quality (MDEQ) has identified Bee Lake as not meeting its designated use of Aquatic Life Support. Water bodies that have been identified as not meeting their designated use are listed as impaired as required by Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR Part 130). The lake (water body MS361BLM1) is on the Mississippi Section 303(d) list as impaired due to sediment/siltation, organic enrichment/low DO, and nutrients. Mississippi does not have standards for allowable nutrient concentrations, so a Total Maximum Daily Load (TMDL) specifically for nutrients will not be developed. However, because elevated levels of nutrients may cause low levels of dissolved oxygen (DO), the TMDL developed for organic enrichment/low DO also addresses the potential impact of elevated nutrients in the water body.

Section 303(d) requires the development of TMDLs for those water bodies contained on the impaired waters list. A TMDL is the sum of the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of those impaired water bodies through the establishment of pollutant-specific allowable loads. The water quality standard for Sedimentation/Siltation is narrative. The water quality standard for DO is a daily average of 5.0 mg/L, with an instantaneous minimum of not less than 4.0 mg/L.

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, several analytical tools were used in combination. Assessments of the nonpoint source loading into the lake were developed for the Bee Lake watershed using the Generalized Watershed Loading Function (GWLF) computer program. GWLF provided estimates of nutrients and sediments transported to the lake for individual land use categories. The lake was evaluated using the CE-QUAL-W2 water quality simulation computer model to estimate the concentrations of DO and oxygen-consuming constituents. The lake was segmented into a total of 18 segments to represent the system.

Model results were evaluated for the period from 1997 to 2000, which presented a range of climatic conditions. The year 1997, which was a predominantly wet year, was identified to be the critical period for the TMDL, that is, reflective of the poorest water quality conditions in the lake. Model segment 9 was chosen as the location for evaluating the TMDL. This segment includes the sampling location where data were collected and it is assumed to be representative of the lake.

For this TMDL, the loadings of oxygen-demanding material are given in terms of total ultimate biochemical oxygen demand (TBODu). TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous

compounds under aerobic conditions. According to the model, no decrease in oxygen-demanding source loadings or TBODu coming from the watershed is needed to meet the prescribed DO criteria of a daily average of 5 mg/L. The target for sedimentation/siltation was selected as a range of values, from 0.07 cm/year to 0.04 cm/year. It should be noted, however, that the reductions specified in this TMDL report represent just one example of how pollutant loadings could be modified in order to improve water quality in Bee Lake. Watershed management scenarios other than those included in this report are possible. Little hydrological and water quality data are available for Bee Lake, and the management scenarios could be modified based on a reevaluation of the data and modeling if these data become available. At present, it is anticipated that some reductions of the current load can be achieved through a combination of land use and restoration practices such as erosion and sediment control practices, reduced tillage practices on croplands, forest management, and stream restoration.

The TMDLs for sedimentation/siltation have been expressed in terms of tons/acre/year. According to 40 CFR section130.2 (i), TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measure. In this case, an "other appropriate measure" is used to express the TMDL as the tons of sediment that can be discharged from an acre of a subwatershed per year (tons/acre/year) and still attain the applicable water quality standard. This results in a range of acceptable reference yields of 0.33 to 0.20 tons/acre/year. For this TMDL, it is appropriate to apply the same target yield to permitted waste load allocation (WLA) and unpermitted load allocation (LA) watershed areas. For load TMDLs, the WLA and LA are summed to calculate the TMDL. Because this TMDL is expressed as a yield, as long as all activities, permitted or unpermitted, meet the same yield, the TMDL will be met, regardless of the relative load contribution.

Wet weather sources of sediment, which are discharged to a receiving water body as a result of the storm events, are considered to be the primary concern for this sediment TMDL. These wet weather sources can be broadly defined, for the purposes of this TMDL, into two categories: wet weather sources regulated by the National Pollutant Discharge Elimination System (NPDES) program, and wet weather sources *not* regulated by NPDES. Wet weather sources regulated by the NPDES program include industrial activities (which include certain construction activities), and discharges from Municipal Separate Storm Sewer Systems (MS4s). The wet weather NPDES-regulated sources are provided a wasteload allocation (WLA) in this TMDL, and all other wet weather sources of sediment (those not regulated by NPDES) are provided a Load Allocation (LA).

There are no municipal, industrial, or commercial facilities in the Bee Lake watershed with NPDES permits that are permitted for Total Suspended Solids (TSS). If present, it would not be appropriate to include these facilities since these sources provide negligible loadings of sediment to the receiving waters compared to wet weather sources (e.g., NPDES-regulated construction activities, MS4s, and nonpoint sources). Also, the TSS component of a NPDES-permitted facility is different from the pollutant addressed within this TMDL because the TSS component of the permitted discharges is generally composed more of organic material, and therefore, provides less direct impact on the biologic integrity of a stream (through settling and accumulation) than would stream sedimentation due to soil erosion during wet weather events. The pollutant of concern for the sedimentation TMDL is sediment from land use runoff.

Any future WLAs provided to NPDES municipal and industrial permitted dischargers will be implemented through the state's NPDES permit program and are not included in this TMDL. The wet weather WLAs provided to the NPDES-regulated construction activities and MS4s will be implemented through Best Management Practices (BMPs) as specified in Mississippi's General Stormwater Permits for Small Construction, Construction, and Phase I and II MS4 permits, which can be found on the MDEQ Web site (www.deq.state.ms.us). It is not technically feasible to incorporate numeric sediment limits into permits for these activities and facilities at this time. LAs for nonpoint sources will be achieved through the voluntary application of BMPs. Properly designed and well-maintained BMPs are expected to leads to the attainment of the wet weather WLAs and LAs.

The TMDLs are presented in Tables ES-1, ES-2 and ES-3. The margin of safety (MOS) has been addressed through implicit assumptions.

Table ES-1. TMDL for TBODu for Bee Lake

Pollutant	WLA (lbs/day)	LA (lbs/day)	MOS (lbs/day)	TMDL (lbs/day)
CBODu	0	149	Implicit	149
NBODu	0	85	Implicit	85
TBODu	0	234	Implicit	234

Table ES-2. TMDL for Sedimentation Rate of 0.07 cm/year for Bee Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.33	0.33	Implicit	0.33

Table ES-3. TMDL for Sedimentation Rate of 0.04 cm/year for Bee Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.20	0.20	Implicit	0.20

1.0 Problem Understanding

The identification of water bodies not meeting their designated use and the development of total maximum daily loads (TMDLs) for those water bodies are required by Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA) Water Quality Planning and Management Regulations (40 CFR Part 130). A TMDL is the sum of the allowable amount of a single pollutant that a water body can receive from all contributing point and nonpoint sources and still meet water quality standards. The process is designed to restore and maintain the quality of those impaired water bodies through the establishment of pollutant-specific allowable loads.

The Water Quality Assessment Branch of the Mississippi Department of Environmental Quality (MDEQ) has identified Bee Lake as being impaired as reported in the Mississippi 1998 Section 303(d) List of Water bodies. The lake (water body MS361BLM1) is listed as impaired as a result of sediment/siltation, nutrients, and organic enrichment/low dissolved oxygen (DO).

This report presents both the approach undertaken to develop TMDLs for Bee Lake and a review of the potential causes of impairment and the required TMDL components.

1.1 Lake Description

Oxbow lakes are formed by a long, erosional process within a meandering stream. Meandering streams possess a sinuous channel with broadly looping curves that possess an unequal distribution of flow velocity. As a consequence of the unequal velocities, the outer bank is eroded and sediment deposition occurs along the opposite side of the channel. The net effect is that the meander migrates laterally. Over time the channel becomes so sinuous that the land separating the adjacent meanders becomes very narrow. During a flood, the stream will abandon its channel, cutting through the narrow strip of land, and flow the shorter distance (Monroe and Wincander, 1992). Sediment transported by the stream is deposited along the new stream bank at the site of the abandoned meander. Once the abandoned meander is completely isolated from the main channel, it becomes an oxbow lake. Over time, oxbow lakes naturally fill with sediment. . Figure 1-1 below demonstrates this process. Over time, oxbow lakes naturally fill with sediment.

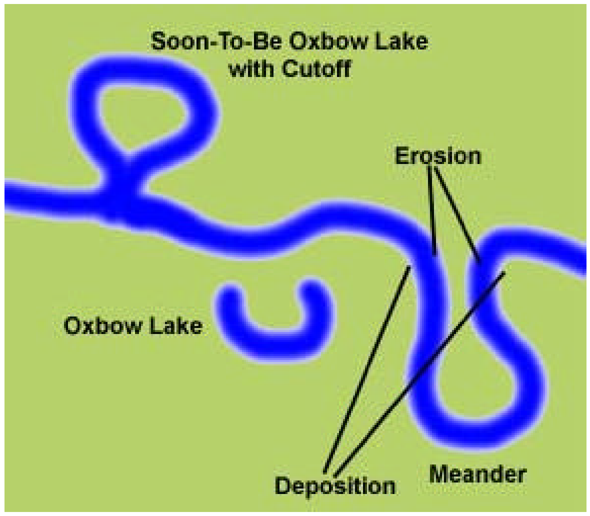

Figure 1-1. Oxbow Lake Creation Process

Bee Lake is an elongated oxbow lake that was formed on an abandoned arm of the Yazoo River. Inflow is through canals linked to Tchula Lake. Outflow is through a canal with a weir installed that is linked to Tchula Lake, near where Tchula Lake meets the Yazoo River, and through canals that discharge to the Yazoo River directly. Morphometric and hydraulic data for Bee Lake are shown in Table 1-1.

Table 1-1. Morphometric and Hydraulic Characteristics of Bee Lake

Parameter	Measured
Surface area (ac)	1,198
Drainage area (ac)	11,870 (18.5 mi^2)
Depth Mean Lake (m) Maximum Lake (m)	 2.5 (8.2 ft) 4 (13 ft)

Source: Surface area – GIS coverage
Drainage area – topographic data
Depth – Bathymetric Map

1.2 303(d) Listed Water bodies

Bee Lake (MS361BLM1) is listed on the State's 303(d) list of impaired water bodies (Table 1-2).

Table 1-2. 303(d) Listing

Water body Name	Water body ID	Location	Beneficial Use	Impairment
Bee Lake	MS358BLM	Holmes	Aquatic Life Support	Sediment/Siltation Nutrients, and Organic Enrichment/Low DO

Excessive sedimentation from anthropogenic sources is a common problem that can impact water bodies in a number of ways. In the Mississippi Valley, suspended sediment and turbid conditions caused by suspended sediment are a primary water quality concern

(MDEQ, 1999). Suspended sediment can impact lake and stream biota in various ways. Deposited sediments reduce habitat complexity by filling in pools, riffle areas, and the interstitial spaces used by aquatic invertebrates. Elevated turbidity reduces the light penetration necessary for photosynthesis in aquatic plants, reduces the feeding efficiency of visual predators and filter feeders, and lowers the respiration capacity in aquatic invertebrates by clogging gill surfaces. In addition, other contaminants such as nutrients and pesticides can be transported to lakes and streams during runoff events while attached to sediment particles.

DO has historically been used as the constituent that measures or indicates the overall quality of surface water. DO analysis measures the amount of gaseous oxygen dissolved in an aqueous solution, which enters the water by diffusion from the surrounding air, by aeration (rapid movement), and as a waste product of photosynthesis. Adequate DO is essential for good water quality and is a necessary element to all forms of life. Decreases in the DO concentrations can cause changes in the types and numbers of aquatic macroinvertebrates that live in a water ecosystem. As the DO levels decrease, pollution-intolerant organisms are replaced by pollution-tolerant worms and fly larvae and there is a decline in the number of species that cannot tolerate decreases in DO (Ricklefs, 1990).

Oxygen is used by plants and animals for respiration. Aerobic bacteria consume oxygen during the process of decomposition. When organic matter and nutrients such as animal waste, fertilizer, or improperly treated wastewater enter a body of water, they are used by the bacteria within the streambed and the algae in the water column (Ricklefs, 1990; Wetzel, 1983). Algae and bacteria use the organic matter and nutrients for growth. The DO concentration decreases as the plant material dies off and is decomposed through the action of the aerobic bacteria.

Nutrient transport is governed by several chemical, physical, and biological processes known as the nutrient cycle. The nitrogen cycle consists of four processes (nitrogen fixation, ammonification, nitrification, and denitrification) that convert nitrogen gas into usable nitrogen forms and back into nitrogen gas. Nitrogen fixation converts gaseous nitrogen into ammonia while ammonification involves the breakdown of wastes and nonliving organic tissue into ammonia. The nitrification process oxidizes ammonia that results in nitrate and nitrite. Finally, nitrates are converted back into gaseous nitrogen through the denitrification process. Ammonia ions, nitrites, and nitrates are most important for water quality assessments because of their impact on water quality. The conversion of ammonia to nitrate consumes 4.57 pounds of oxygen for every pound of ammonia (USEPA, 1993).

Instream DO concentrations fluctuate daily. The diurnal variations in DO concentrations are mainly due to photosynthesis and respiration of aquatic plants such as phytoplankton, aquatic weeds, or algae (Chapra, 1997; Wetzel, 1983). Photosynthesis is the process by which plants use solar energy to convert simple inorganic nutrients into more complex organic molecules. Because of the need for solar energy, photosynthesis occurs only during daylight hours and is represented by the following simplified equation:

$6CO_2$ +	$6H_2O$	<--------->	$C_6H_{12}O_6$ +	$6O_2$
(Carbon dioxide)	(Water)		(Sugar)	(Oxygen)

In this reaction, photosynthesis is the conversion of carbon dioxide and water into sugar and oxygen such that there is a net gain of DO in the water body (Ricklefs, 1983). Conversely, respiration and decomposition operate the process in reverse and convert sugar and oxygen into carbon dioxide and water resulting in a net loss of DO to the water body. Respiration and decomposition occur at all times and are not dependent on solar energy. Water bodies exhibiting the typical diurnal variation of DO experience the daily maximum in mid-afternoon during which time photosynthesis is the dominant mechanism and experience the daily minimum in the predawn hours during which respiration and decomposition have the greatest effect on DO and photosynthesis is not occurring (Wetzel, 1983).

1.3 Water Quality Standards and Beneficial Uses

The beneficial use identified for Bee Lake is Aquatic Life Support (MDEQ, 2002). Although there are no specific applicable criteria for this beneficial use, the criteria listed in Table 1-3 apply to all surface waters in Mississippi. The water quality objectives provide both a narrative and numeric basis for identifying appropriate TMDL endpoints for sedimentation/siltation and organic enrichment/low DO.

Table 1-3. Relevant Water Quality Objectives

Section	**Water Quality Objective**
Section II.3	Waters shall be free from materials attributed to municipal, industrial, agricultural or other discharges producing color, odor, taste, total suspended or dissolved solids, sediment, turbidity, or other conditions in such degree as to create a nuisance, render the waters injurious to public health, recreation or to aquatic life and wildlife or adversely affect the palatability of fish, aesthetic quality, or impair the waters for any designated use.
Section II.7	DO concentration shall be maintained at a daily average of not less than 5.0 mg/L with an instantaneous minimum of not less than 4.0 mg/L. When possible, samples should be taken from ambient sites according to the following guidelines: • For waters that are not thermally stratified, such as unstratified lakes, lakes during spring turnover, streams, and rivers. At mid depth if the total water column is 10 feet or less and at 5 feet from the water surface if the total water column is greater than 10 feet. • For waters that are thermally stratified such as lakes, estuaries, and impounded streams. At mid depth if the epilimnion is 10 feet or less and at 5 feet from the water surface if the epilimnion depth is greater than 10 feet.

1.4 Watershed Description

The Bee Lake watershed, which is part of U.S. Geological Survey (USGS) Hydrologic Unit Code (HUC) 08030206, encompasses approximately 18.5 square miles (11,870 acres). It is located in Holmes County southeast of Lexington, Mississippi (Figure 1-2).

The highest area of the watershed, with a peak of approximately 115 feet above mean sea level (MSL), is located in the northeast. The lowest points are near Bee Lake, at approximately 90 feet MSL. Land use in the watershed is predominantly agricultural. The major crops within the watershed are corn, cotton, rice, sunflowers, sorghum, soybeans, other small grains, winter wheat, and snap beans, with cotton being the major crop. It includes a number of man-made aquaculture ponds that are used for raising catfish. Most of the aquaculture ponds are located in the southern portion of the watershed.

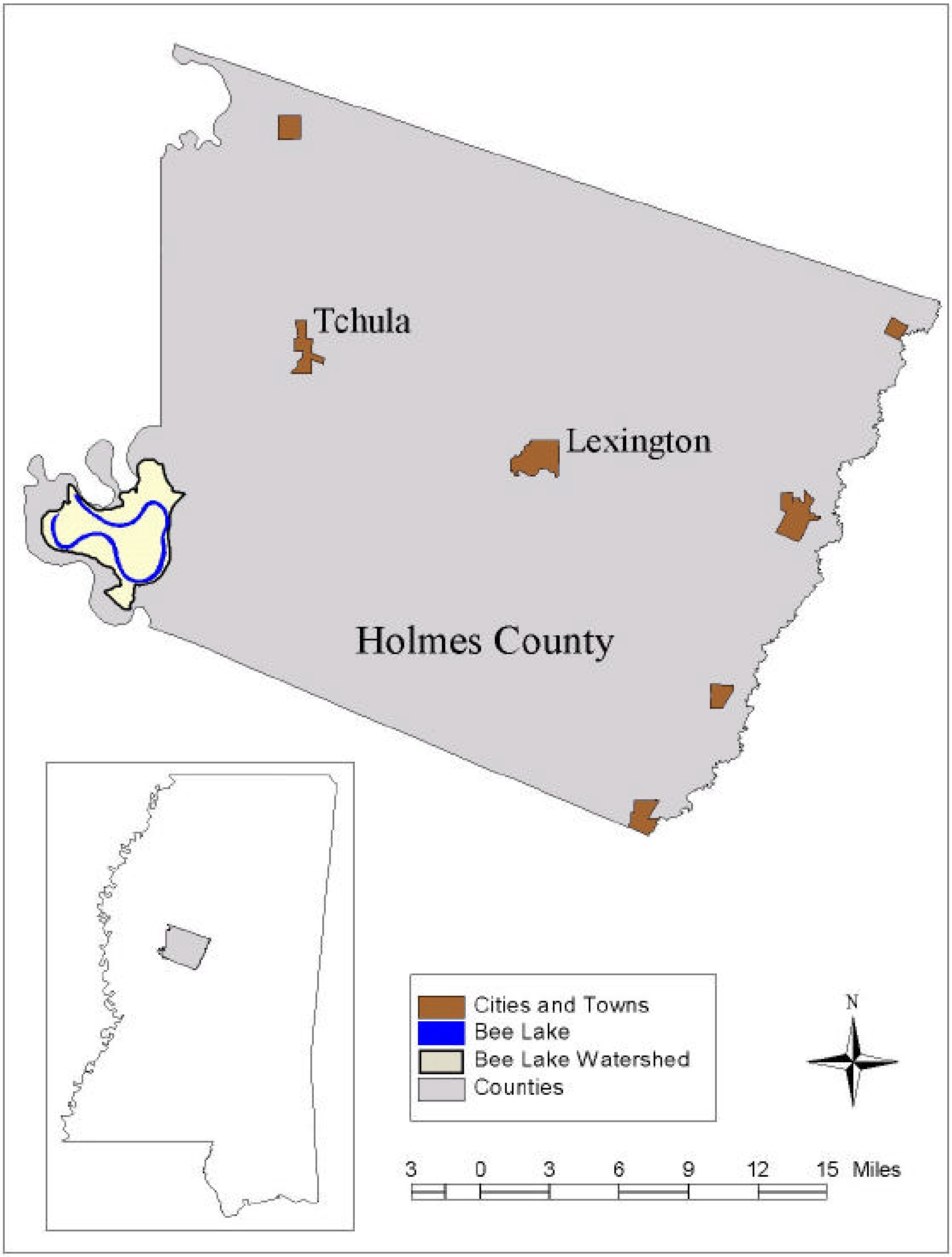

Figure 1-2. Watershed Location

1.4.1 Topography

The Bee Lake watershed is relatively flat, with only a 25-foot difference between its highest point and its lowest point. The highest point is in the northeastern portion of the watershed at an elevation of approximately 115 feet above mean sea level (MSL). The lowest point, about 90 feet MSL, is in the north central portion of the watershed, just north of Bee Lake. Bee Lake is approximately 100 feet MSL. Figure 1-3 shows the digital elevation map for the Bee Lake watershed.

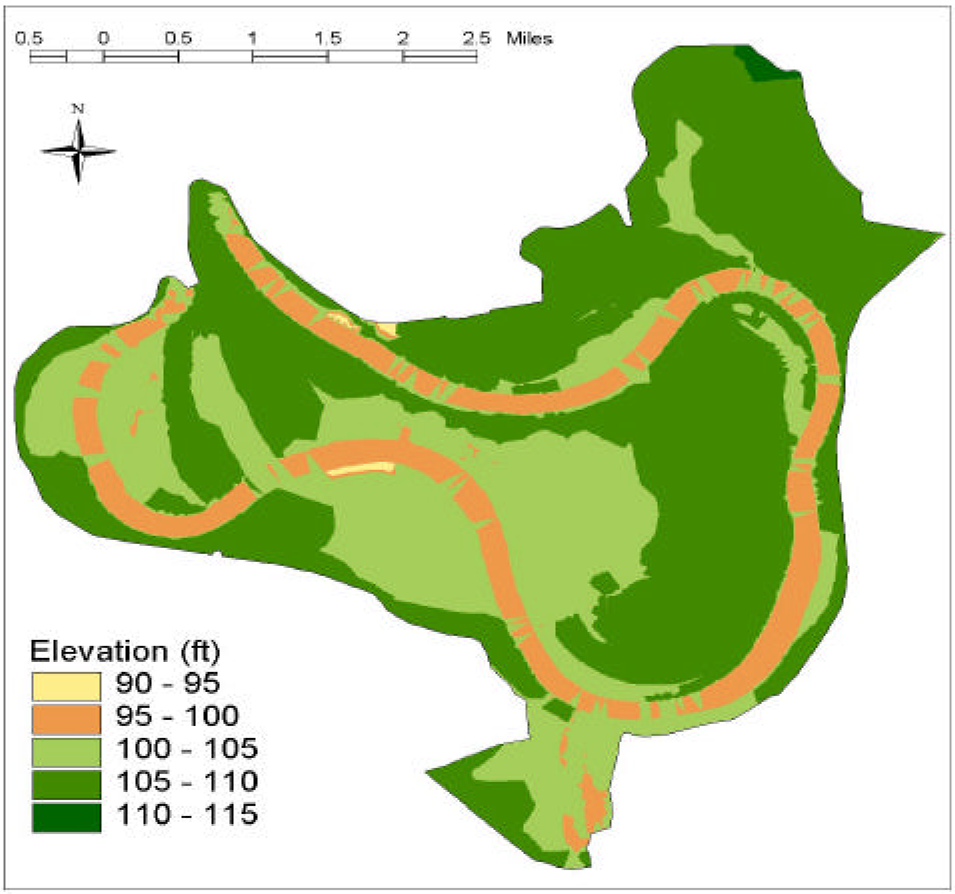

Figure 1-3. Digital Elevation Map

1.4.2 Soil Type

There are two soil types in the Bee Lake watershed: Sharkey-Forestdale-Dundee (MS017) and Dundee-Forestdale-Dubbs (MS029). These soil groups are presented in Figure 1-4 and Table 1-4. The Dundee-Forestdale-Dubbs soil covers the majority of the watershed. The infiltration rates for these types of soil groups are characterized by slow to extremely slow permeability and a soil erodibility factor (K) of 0.34 to 0.42.

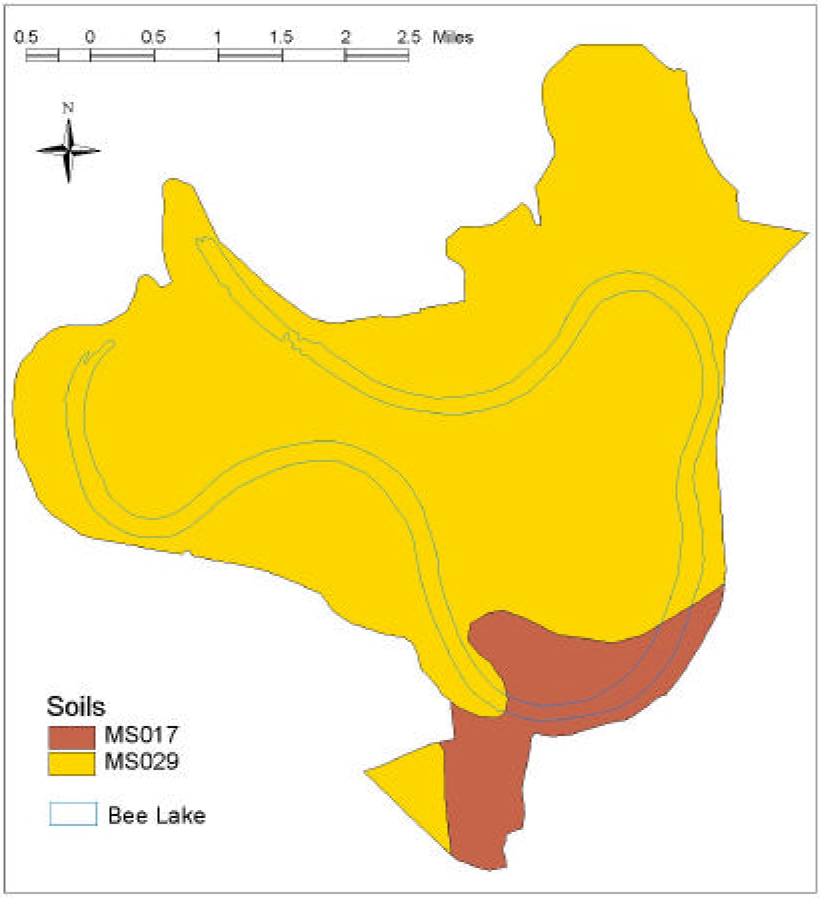

Figure 1-4. Soil Type

Table 1-4. Soil Types

Soil Type	Soil Name	Area (acres)
MS017	Sharkey-Forestdale-Dundee	1,182
MS029	Dundee-Forestdale-Dubbs	10,688
Total		**11,870**

1.4.3 Land Use

The Bee Lake watershed consists of approximately 97 percent cropland, bottomland hardwood forest, or water, of which 73 percent is cropland. Of the remaining 3 percent, farmed wetlands and pasture/grasslands are the largest land uses. Riverine swamp, bottomland hardwood forests, farmed wetlands, and water are the predominant land uses in areas that are lower than the surrounding area. Figure 1-5 and Table 1-5 present the land use areas in the watershed.

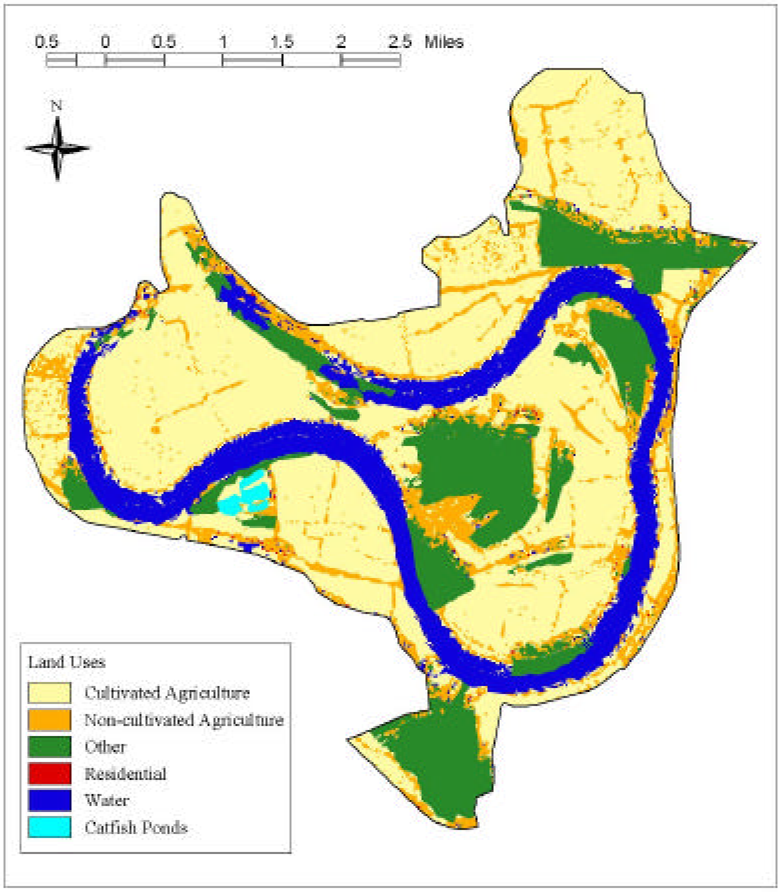

Figure 1-5. Mississippi Automated Resource Information System Land use

Table 1-5. Land Use

Land Use	**Area (acres)**	**Area (%)**
Catfish Ponds	79	1
Cultivated Agriculture	6,091	51
Non-cultivated Agriculture	1,707	14
Other	2,622	22
Residential	173	1
Water	1,198	10
Total	11,870	~100

1.5 Climate Characteristics

Mississippi is located in the humid subtropical climate region, characterized by temperate winters and long, hot summers; rainfall occurs more often in the winter and early spring. Late summer and fall are typically the driest times of the year. The state, however, is subject to periods of both drought and flood. Prevailing southerly winds provide moisture for high humidity from May through September. The potential for locally violent and destructive thunderstorms averages about 60 days each year. Eight hurricanes have struck Mississippi's coast since 1895, and tornadoes are a particular danger, especially during the spring season (MS State Climatologist, 2003).

Normal mean annual temperature for the Jackson weather station, which is the closest weather station monitoring daily temperature, is 18^{o}C. Low temperatures have dropped to 4^{o}C, while the maximum temperatures have reached 29^{o}C. Mississippi, in general, has a climate characterized by the absence of severe cold in winter but the presence of extreme heat in summer. The ground rarely freezes and outdoor activities are generally planned year-round. Cold spells are usually of short duration, and the growing season is long (MS State Climatologist, 2003).

1.6 Socioeconomic Characteristics

The social and economic region for Bee Lake is Holmes County, a sparsely populated area covering 756 square miles and having only 29 persons per square mile (US DOC, Census, 2002). Comparatively, Mississippi has 61 persons per square mile and the United States has 80 persons per square mile. The largest source of jobs in the area is in the government sector (which includes federal, state, and local government), accounting for 22.9 percent of total employment, followed closely by the services sector at 22.8 percent of total employment. The services industry includes establishments primarily engaged in providing a wide variety of services, such as hotels and other lodging places; establishments providing personal, business, repair, and amusement services; health, legal, engineering, and other professional services; educational institutions; membership organizations; and other miscellaneous services (OSHA, 2001). The retail trade sector is the third largest employer, providing 15.5 percent of the total number of jobs, followed by the farming sector, which accounted for 12.7 percent, and then manufacturing at 12.5 percent. Farming in the region includes row crops such as cotton, corn, soybeans, rice, and sorghum. Catfish farming is also a growing animal agricultural industry in the Mississippi Delta area.

Bee Lake attracts recreational fishermen, who contribute to the services sector of the regional economy. Recreational visitors benefit the local economy through expenditures on food, lodging, and sporting goods. The lake has one pay-to-launch boat ramp (MDWFP, 2003).

1.7 Threatened or Endangered Species Within the Watershed

Information on endangered species found within the Bee Lake watershed was obtained from the Mississippi Department of Wildlife, Fisheries, and Parks. There is one species of concern, the Paddlefish (*Polyodon Spathula*), found in Bee Lake (Mississippi Natural Heritage Program, 2000).

2.0 Data Summary

This section provides an inventory, description, and review of the data compiled to support Total Maximum Daily Load (TMDL) development, as well as a brief description of data limitations.

2.1 Data Inventory

Tables 2-1 and 2-2 identify available data used to support the TMDL development effort. The two tables represent the major categories of data: geographic or location information and monitoring data. Data include water quality observations, sediment source information, land use, and meteorological data.

Table 2-1. Available Geographic or Location Information

Type of Information	Data Source(s)[a]
Stream network	USEPA BASINS (Reach File, Versions 1 and 3); USGS NHD reach file; MARIS
Land use	MARIS
Cities/populated places	BASINS; MARIS; U.S. Census
Counties	BASINS; MARIS
Soils	BASINS (USDA-NRCS STATSGO); MARIS
Watershed boundaries	BASINS (8-digit hydrologic cataloging units); MARIS
Topographic and digital elevation models (DEMs)	BASINS (DEM); USGS digital raster graphs
Aerial photos	MARIS
Roads	BASINS; MARIS
Ecoregions	BASINS (USDA Level 3 ecoregions)
Water quality station locations	BASINS
Meteorological station locations	BASINS; NOAA-NCDC
Stream gage stations	BASINS; USGS
Surface geology	MARIS
Dam locations	MARIS
Impaired water bodies (303(d)-listed segments)	MDEQ

[a] USEPA = U.S. Environmental Protection Agency, BASINS = Better Assessment Science Integrating Point and Nonpoint Sources, USGS = U.S. Geological Survey, NHD = National Hydrography Dataset, MARIS = Mississippi Automated Resource Information System, MDEQ = Mississippi Department of Environmental Quality, USDA-NRCS = U.S. Department of Agriculture, Natural Resources Conservation Service, NOAA-NCDC = National Oceanic and Atmospheric Administration, National Climatic Data Center, NHD = National Hydrography Dataset.

Table 2-2. Available Monitoring Data

Type of Information	Data Source(s)
Water body Characteristics	
Physical data	BASINS (Reach File, Versions 1 and 3); USGS NHD Reach data
Flow	
Historical flow record	USGS (gage sites located near but not in watersheds)
Meteorological data	
Rainfall	NOAA-NCDC, Earth Info
Temperature	NOAA-NCDC, Earth Info
Water quality data (surface water, groundwater)	
Water quality monitoring data	MS Office of Pollution Control, 1994 Clean Lakes Survey MS Office of Pollution Control, 1995 Clean Lakes Survey

2.2 Monitoring Data Assessment of Bee Lake

There are limited monitoring data for Bee Lake. Both the 1994 and 1995 Clean Lakes Surveys sampled Bee Lake only on one occasion at one station each. The relevant data are listed below in Table 2-3.

Table 2-3. Available Water Quality Monitoring Data

Parameter	1994 Clean Lakes Survey Monitoring Data	1995 Clean Lakes Survey Monitoring Data
Sample date	20 June 1994	11 July 1995
Sample time	14:40	11:15
Conductivity (µmhos/cm)	57	59
pH	8.2	7.8
Hardness (mg $CaCO_3$/L)	28	23
Alkalinity (mg $CaCO_3$/L)	37	23
Secchi disk (cm)	35	65
TKN (ppm)	0.92	1.55
NH_3-N (ppm)	0.16	<0.1
NO_2+NO_3 (ppm)	<0.04	<0.04
Total phosphorus (ppm)	0.2	0.08
TOC (ppm)	5.0	5.0
Chlorophyll a (µg/L)	Not sampled	36.57

DO and temperature were also sampled during both surveys, with measurements taken at four depths. The data are listed in Table 2-4.

Table 2-4. Available DO and Temperature Data

	DO (mg/L)		**Temperature (ºC)**	
Depth (m)	1994	1995	1994	1995
Surface	8.7	9.2	31.3	32
1	3.3	8.9	28.0	31
2	0.6	2.8	27.5	29
2.5	<0.1		26.0	
3		0.7		27

3.0 Source Assessment

This section describes the potential sources in the Bee Lake watershed. The source assessment, along with the available data for Bee Lake described in the previous section was used as the basis of development of the model and analysis of the TMDL allocation. The potential point and nonpoint sources are characterized by the best available information and literature values. This section documents all available information.

3.1 Point Sources

Pollutant sources under the Clean Water Act (CWA) are typically categorized as either point or nonpoint sources. Point sources, according to 40 CFR 122.3, are defined as any discernible, confined, and discrete conveyance, including but not limited to, any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, concentrated animal feeding operation, landfill leachate collection system, vessel, or other floating craft from which pollutants are or may be discharged. The National Pollutant Discharge Elimination System (NPDES) Program, under CWA Sections 318, 402, and 405, requires permits for the discharge of pollutants from point sources. There are several types of permits under the NPDES permit program: effluent from facilities, municipal wastewater treatment plants, storm water from construction sites, and municipal separate storm sewer systems (MS4s).

As of March 2003, the discharge of storm water from construction activities disturbing between 1 and 5 acres must also be authorized by an NPDES permit, in addition to the requirements already in place for larger construction sites. The purpose of these NPDES permits is to eliminate or minimize the discharge of pollutants from construction activities. Since construction activities at a site are of a temporary, relatively short-term nature, the number of construction sites covered by the general permit at any point in time varies. The target for these areas is the same range as the TMDL target of 0.75 to 0.44 tons per acre per year. The Waste Load Allocations (WLAs) provided to the NPDES-regulated construction activities and MS4s will be implemented as Best Management Practices (BMPs) as specified in Mississippi's General Storm water Permits for Small Construction, Construction, and Phase I & II MS4 permits. It is not technically feasible to incorporate numeric sediment limits into construction storm water or MS4 permits at this time. WLAs should *not* be construed as numeric permit limits for construction or MS4 activities. Properly designed and well-maintained BMPs are expected to provide attainment of WLAs.

A review of the Mississippi automated resource information system discharge elimination file determined that no permitted point source discharges are located within the watershed. The towns within the Bee Lake watershed are small and, according to the final Phase II Storm water NPDES regulations, are not considered regulated small MS4s at the present time. However, the potential for sediment loadings from NPDES-regulated construction activities and MS4s is considered a point source of sediment to surface waters. These discharges occur in response to storm events and are included in the WLA of this TMDL.

3.2 Nonpoint Source Data

Nonpoint sources in the watershed may also contribute pollutants to the lake and its tributaries. Nonpoint sources represent contributions from diffuse, nonpermitted sources. Exceptions to this are where some aquaculture facilities (which are discrete and non-permitted sources), and where storm water collection systems are in place regulating the runoff as a point source, since the runoff is delivered to the receiving water body through a conduit. Nonpoint sources include both precipitation driven and non-precipitation-driven events, such as contributions from groundwater; septic systems; direct deposition of pollutants from wildlife, livestock, or atmospheric fallout.

Nonpoint sources contribute sediment and oxygen-consuming loads into the waters of the Bee Lake watershed. On the land surface, oxygen-consuming constituents accumulate over time and wash off during rain events. As the runoff transports the sediment over the land surface, more oxygen-consuming constituents are collected and carried to the stream. The net loading into the stream is determined by the local watershed hydrology.

3.2.1 Agricultural Sources

The Mississippi Valley is one of the most intensively agricultural areas in the United States. The flat, fertile soils produce a variety of crops including cotton, corn, and soybeans (Rebich, 1999).

Cultivated and noncultivated agricultural lands cover 51 percent and 14 percent of the Bee Lake watershed area, respectively. Cotton is the major crop in the Bee Lake watershed, representing 53 percent of the total cultivated agriculture land. Additional crops include: corn, soy beans, sorghum, snap beans, other small grains, rice, winter wheat, and sunflowers.

Farming practices, including frequent tillage, and over grazing diminish vegetative cover and result in the elevated loading of sediment and oxygen-consuming constituents in nearby water bodies. Agricultural Best Management Practices (BMPs) such as buffer strip, conservation tillage, and the proper land application of animal wastes reduce the amount of sediment and oxygen-consuming constituents loading to water bodies.

3.2.2 Aquaculture

The production of catfish is the largest aquaculture enterprise in the United States. Catfish ponds located in the Mississippi Valley account for approximately 78 percentage of the total land area devoted to catfish production (USEPA, 2002). The majority of the catfish ponds in the Mississippi Valley are groundwater-fed, earthen levee ponds. The discharge of sediments rich in oxygen-consuming substances from catfish ponds occurs during drainage and overflow events. Drainage occurs occasionally, an average of once every 6 years for most ponds, when ponds are drained for harvesting or structural repairs. However, overflow from ponds occurs more often, when the pond level rises due to precipitation events. Therefore, in this analysis, the ponds are treated as nonpoint sources. Common pond management practices that reduce the frequency of pollutant discharges include managing pond levels to maintain water storage potential and reducing the frequency of pond drainage for cleaning and repairs. These practices are currently used in most catfish ponds in Mississippi (Tucker et al, 1996). A complex of catfish ponds covering approximately 79 acres, less than 1 percent of the watershed area, is present in the Bee Lake Watershed.

3.2.3 Septic Systems

Failing septic systems represent a source that may contribute oxygen-consuming constituents to receiving water bodies through surface or subsurface malfunctions. Quantifying loading from actual failing septic systems and potential illegal discharges is difficult. Since the number of dwellings within the lake's watershed is small, septic systems were omitted from the analysis.

Holmes County has a total of 8,439 housing units (Table 3-1). Approximately 1.6 percent of the housing units within the county lacked complete plumbing facilities. Because of this low percentage, septic systems were omitted from the analysis.

Table 3-1. Regional Housing Characteristics

	Holmes County	**Percent**
Total housing units	8,439	100.0
1-unit detached	5,248	62.2
In building with 10 or more units	130	1.5
Mobile homes	2,265	26.8
Lacking complete plumbing facilities	118	1.4
Occupied units	7,314	86.7
Vacant units	1,125	13.3
For seasonal, recreational, or occasional use	358	4.2

Source: US DOC, Census, 2001.

3.2.4 Groundwater

The Mississippi River alluvial aquifer underlies the Mississippi River alluvial plain locally known as the Delta. The alluvial aquifer is the most heavily pumped aquifer in Mississippi (Arthur, 2001), of which 98 percent is for agriculture. According to the USGS, "the aquifer receives water vertically from precipitation, internal stream and lakes, and locally from the Cockfield and Sparta aquifers where they directly underlie the alluvial aquifer. The alluvial aquifer also discharges water to the underlying aquifers, and during extended periods with no surface runoff, to the Mississippi River and to the internal streams and lakes"(Arthur, 2001).

The water quality of the alluvial aquifer is well suited for agriculture but less suited for municipal and some industrial use. It is commonly a hard, bicarbonate type. It contains appreciable amounts of manganese and dissolved iron concentrations usually greater than 3.0 mg/L. According to the USGS, nutrient concentrations are generally low. All nitrate concentrations have been below the USEPA drinking water standard of 10 mg/L (Kleiss et al, 1999).

3.2.5 Background Sources

A TMDL load allocation must consider the natural background loading of a pollutant. For this TMDL, the contribution of sediment and organic material from forested areas was considered be the background load. Forested land, including bottomland hardwood forest, upland scrub, and riverine swamp, covers 22 percent of the Bee Lake watershed. Sediment contributions are generated from forested areas and other nonanthropogenic areas. While present, they are generally lower than those from disturbed land uses. Forested areas that are subject to silviculture and other forestry activities may exhibit elevated sediment contributions. The monitoring data for the Bee Lake watershed were insufficient to separate natural forest loadings from other forest sources.

The yield of oxygen-consuming substances from forested land is generally low compared to other land uses because the dense vegetative cover stabilizes soil, reduces rainfall impact, and in many cases encourages uptake of nutrients.

4.0 Technical Approach

The objective of this section is to present the key issues considered for TMDL development, and the technical approaches that fulfill the TMDL requirements.

4.1 Technical Approach Selection

The technical approach selected for TMDL development was based on an evaluation of technical and regulatory criteria (EPA, 1991). Technical criteria refer to the model's simulation of the physical system in question, including watershed and/or stream/lake characteristics or processes and constituents of interest. Regulatory criteria make up the constraints imposed by regulations, such as water quality standards or the procedural protocol.

The key technical factors that were considered in identifying the appropriate analytical approach for the sediment/siltation impairments include the following:

- Sediment loads are contributed only by nonpoint sources.
- Erosion and sediment transport generally occur as a result of rainfall events.
- Sedimentation problems in the lake are a cause of cumulative contributions.
- Insufficient monitoring data are available in the watershed to evaluate the magnitude of stream channel and stream bank erosion.

Key technical factors that were considered in identifying the appropriate analytical approach for the nutrient and organic enrichment/low DO impairments include:

- Oxygen-demanding substances (including nutrients) are contributed only by nonpoint sources.
- Oxygen-demanding substances are contributed both from the land surface (as a results of rainfall events) and from the subsurface (resulting from groundwater contributions).
- The annual load of oxygen-demanding substances is responsible for the accumulated benthic blanket of the water body, which in turn, is expressed as Sediment Oxygen Demand (SOD).

A properly designed and applied technical approach provides the source-response linkage component of the TMDL and enables accurate assimilative capacity assessment and allocation proposition. A water body's assimilative capacity is determined through adherence to predefined water quality criteria (i.e., regulatory considerations). Mississippi's applicable water quality standards were presented earlier in this report and provide the basis for establishing appropriate TMDL targets. For sediment/siltation, these standards are narrative; however, for low DO, they are numeric. The instream DO target for this TMDL is a daily average of not less than 5.0 mg/L. The instantaneous minimum portion of the DO standard was considered when establishing the instream target for this TMDL. However, it was determined that using the daily average standard with the conservative modeling assumptions would be sufficiently protective of the instantaneous minimum standard.

Based on the considerations identified above, the technical approach to address sediment/siltation and organic enrichment/low DO impairments in Bee Lake includes a combination of watershed and lake water quality models:

- A simplified watershed model to predict runoff and loadings of sediment, nutrients, and organic material to the lake to address both sediment/siltation and organic enrichment/low DO impairments.
- A receiving water model of the organic enrichment/low DO in Bee Lake for prediction of instream DO concentrations for comparison to selected endpoints.
- A siltation rate analysis for the lake.

The technical approach to TMDL development must consider the dominant watershed and inlake processes. Pollutant loading in the Bee Lake watershed is primarily from nonpoint or diffuse sources, which are typically rainfall driven and relate to surface runoff and subsurface discharge to a stream. Apart from aquaculture within the watershed, which is treated as a point source, no point sources exist in the watershed. The inlake processes include advective and diffusive transport and nutrient cycling. The approach will provide a hydrologic, sediment, and nutrient loading budget for the watershed that can be linked to an inlake and instream water quality model to assess the inlake water quality.

4.2 Modeling

Both watershed and receiving water models were used to identify the TMDL for sediment and organic enrichment. To facilitate the discussion, the models are discussed by impairment in the following subsections.

4.2.1 Sedimentation

The Generalized Watershed Loading Function model (GWLF) (Haith and Shoemaker, 1987) was selected to simulate the loading of sediment and oxygen-consuming substances from the Bee Lake watershed. The GWLF model has been widely used to estimate sediment and nutrient loads from agricultural watersheds. The GWLF model uses the Soil Conservation Service Curve Number (SCS-CN) approach to model surface runoff and the Universal Soil Loss Equation (USLE) algorithm to model erosion and sediment yield. The SCS-CN and USLE methods are a component of other watershed models including the Agricultural Nonpoint Source Loading (AGNPS) model and the Soil and Water Assessment Tool (SWAT).

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use/land cover scenarios. Each category area is assumed to be homogenous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff plus evapotranspiration. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

The sediment accumulation in Bee Lake can be assessed using trap efficiency calculations. The Brune method (USACE, 1989) provides a widely used trap efficiency estimation method for lakes and reservoirs, using a graphical relationship between trap efficiency and the ratio of water body volume to annual volumetric inflow. Using the volume of the lake and estimated annual inflows from the GWLF model, the trap efficiency (%) of the lake can be estimated. Based on the trap efficiency, the siltation rate can then be estimated. Additional modeling information can be found in Appendix A.

4.2.2 Organic Enrichment/Low DO and Nutrients

The Bee Lake system is fairly long and narrow. Inlake conditions are assumed to vary along the length of the system, and vertical stratification occasionally occurs. The existing calibrated CE-QUAL-W2 (Cole and Buchak, 1995) hydrodynamic model for this system will be used to simulate eutrophication processes. The model is vertically and horizontally two-dimensional and simultaneously simulates hydrodynamics and the transport and transformation of water quality variables. The model was configured with 18 longitudinal segments, ranging in length from 500 to 1,900 meters long, and a maximum of two 1-meter and one ½-meter-thick vertical layers. The total number of active model cells was 53. In general the simulated DO followed a seasonal trend. No calibration could be performed at this time due to lack of inlake monitoring data. Additional information on model calibration (plots and discussion), and additional modeling information about model setup, assumptions, and limitations can be found in Appendix B.

Once the model setup was complete, the model was run for the selected critical period from 1997 to 2000 under baseline conditions. The baseline model run reflects the existing conditions for these years without any reduction to the oxygen-consuming loadings from the watershed. The model simulation results were analyzed at the mid-depth with the daily average DO criteria. The DO standard was applied at mid-depth of the lake, as the average depth of the lake was less than 10 feet. Model segment 9 (Figure B-1 in Appendix B) was chosen as the location for evaluating the TMDL. This segment includes the sampling location where data was collected and was assumed to be representative of the lake.

The model results show that the lake meets the state standard for DO under the baseline conditions. However, since the predicted DO levels are just above 5.0 mg/L, it appears that the lake has reached its assimilative capacity at the present loads. No reductions are recommended for the watershed to achieve the DO water quality at mid-depth. Figures 4-1 shows the baseline case at mid-depth for the daily average DO at segment 9.

Figure 4-1. Daily Average DO in Bee Lake at Mid-Depth.

4.2.3 Modeling Assumptions

Some of the major underlying assumptions for this analysis include the following:

General

- Meteorological data from Jackson, Mississippi, were assumed to be representative of the entire watershed contributing to the lake, although the station is located outside the watershed. The Jackson, MS station was used because it is the station nearest to Bee Lake that has complete meteorological records.
- The watersheds delineated were based on topographic data and available stream and channel coverages. Data regarding flow diversions to or from other watersheds were not available and therefore not considered in the analysis.

Sedimentation Analysis

- The lake's life span was estimated by predicting the amount of sediment contributed to the lake over time and determining the reservoir volume reduced by the sediment. Sediment reaching the lake was assumed to be deposited homogeneously over the entire lake bottom. In reality, however, sediment deposition varies depending on many factors, such as bathymetry. The life of the lake was assumed to be exhausted when the lake surface area was reduced by approximately 50 percent.
- The lake's sediment-trapping efficiency was based on Brune's method (USACE, 1989).

- The sediment distribution was assumed to be an equal mix of sand, silt, and clay particles.
- Sedimentation at the land use level was predicted using USLE, and only a portion of this load was delivered to the lake. The percentage of eroded sediment delivered to the lake was based on a sediment delivery ratio.
- Available data indicated that no timber harvesting was occurring within the watershed. Therefore, forested land was assumed to be consistent throughout the watershed with respect to sediment load contributions.
- Sedimentation prediction assumed that unpaved roads were not playing a major role in sediment contribution to the lake.
- Land management practices including reduced tillage, cover crops and detention ponds are widely used in the Mississippi Delta area (Yuan and Binger, 2002). Therefore, agricultural land in the watershed was assumed to be managed under moderate tillage.

Organic Enrichment/Low DO and Nutrients

- Monthly loads are assumed to sufficiently represent loading variability to the lake model.
- The Wolf Lake kinetic parameters were assumed to be applicable to Bee Lake.
- The watershed model gives an estimate of the total phosphorus and total nitrogen. These loadings were split based on the nutrient ratios determined from inlake monitoring data to provide the required loadings (as per the CEQUAL-W2 model requirements) of dissolved and particulate organic material, ammonia, nitrate-nitrite, and ortho-phosphorous that feed into the W2 model.
- Long-term contributions of nutrients and other oxygen-demanding substances to the lakes ultimately result in high SOD levels.
- The watershed model did not simulate DO and water temperature; therefore, a number of assumptions were made regarding boundary conditions (inputs from the watershed) for the lake model. A DO concentration time series equal to 90 percent saturation was assumed for all inputs.

4.2.4 Limitations

A number of limitations were inherent in the analytical process because of the approach selected. These limitations are identified below. Although these limitations are present, the approach followed successfully resulted in TMDL identification. If additional data are collected for Bee Lake, many of these limitations can be addressed.

Sedimentation Analysis

- Stream-bank erosion was not explicitly considered in the analysis. Only surface erosion and delivery were considered.
- Sediment deposition varies depending on many factors, such as bathymetry. Sediment deposition was assumed to occur evenly over the entire lake area. The life of the lake was assumed to be exhausted when the water volume in the lake surface area was reduced by approximately 50 percent.

- Forested land was assumed to be consistent throughout the watershed, with respect to sediment load contributions.

Organic Enrichment/Low DO and Nutrients

- Sediment nutrient and oxygen flux data for the lake were not available. Collection of these data is important to further understanding of the overall sediment fluxes in the lake and their implications on DO levels. In the event that additional sediment flux data are collected, extending the existing reservoir model to consider predictive sediment diagenesis processes, which dynamically links sediment response to nutrient inputs, could provide a better long-term prediction of SOD. Presently, the CE-QUAL-W2 model does not include a sediment modeling system that directly interacts with the water column; i.e. there is no separate sediment compartment.
- The lake was assumed to be nitrogen limited. This analysis does not consider the possibility that once the nitrogen load is reduced, it is possible that phosphorus will become the limiting nutrient. Without additional monitoring data to support model calibration (i.e, data that quantitatively demonstrate this phenomenon), this shift in nutrient limitation cannot be explicitly modeled.
- The impact of sediment reduction on light extinction in the lake was not considered during the allocation process. It is possible that as sediment loads are reduced, more light will be available to algae in the lake. Light availability may result in increased algae growth and possibly greater DO concentration variability.

4.2.5 Recommendations

Although data collection activities are not planned at present, suggestions for data that could be used to refine the assumptions and address the limitations of the modeling effort are included in this report. Additional data collection would enable a more detailed and refined analysis of sedimentation and DO/organic enrichment dynamics in the lake. These data would ultimately lead to more refined TMDL values and load allocations.

General

- No flow gages are currently located within the watershed. Flow monitoring would provide valuable insight into the watershed's hydrology and support further evaluation of meteorological and land-based impacts on the lake.

Sedimentation Analysis

- Insufficient sediment monitoring data were available to perform a detailed evaluation of sedimentation and resuspension in the lake. Further evaluation of sedimentation spatially and temporally throughout the lake would provide a more precise estimation of the life span.
- Further analysis of stream channel morphology and evolution is recommended to identify the significance of stream-bank erosion to the lake's sedimentation rate. If stream-bank erosion is found to play a major role in sediment contributions to the lake, simulation of stream channel evolution may be a useful analytical tool.
- Additional ground-truthing of unpaved road locations and their impact on sedimentation in the watershed is recommended.

Organic Enrichment/Low DO and Nutrients

- Additional water quality monitoring data within the lake are necessary to support model calibration and to better understand the dynamics of the lake. These data should be collected at multiple locations throughout the lake during different seasons, and they should include depth-variable temperature, DO, and nutrient samples; diurnal DO data; and algal bioassays.
- Water quality monitoring data for tributaries contributing to the lake are important in evaluating locational and source-specific pollutant contributions, as well as identifying seasonal and critical period trends. It is recommended that water quality samples be collected at multiple locations throughout the watershed for baseflow and storm flow conditions.
- The relationship between sediment reduction, light extinction, and algae growth needs to be explored further. Sediment reduction levels, without an associated reduction in nutrients, may result in increased light availability and thus increased algae growth and diurnal DO variations. It is important to collect data that provide more insight into these dynamics.

5.0 TMDL Development

A total maximum daily load (TMDL) for a given pollutant and water body is comprised of the sum of individual wasteload allocations (WLAs) for point sources, and load allocations (LAs) for both nonpoint sources and natural background levels. In addition, the TMDL must include a margin of safety (MOS), either implicitly or explicitly, to account for the uncertainty in the relationship between pollutant loads and the quality of the receiving water body. Conceptually, this definition is represented by the equation:

TMDL = ? ?WLAs + ? ?LAs + MOS

The TMDL is the total amount of pollutant that can be assimilated by the receiving water body while still achieving water quality standards. In TMDL development, allowable loadings from all pollutant sources that cumulatively amount to no more than the TMDL must be established and thereby provide the basis to establish water quality-based controls.

5.1 TMDL Water Quality Endpoints

One of the major components of a TMDL is the establishment of instream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. Instream numeric endpoints represent the water quality goals that are to be achieved by meeting the load allocations specified in the TMDL. The endpoints allow for a comparison between observed instream conditions and conditions that are expected to restore designated uses. Specifications of numeric water quality endpoints or targets are discussed by pollutant below.

5.1.1 Sediment/Siltation

No numeric endpoints are defined in Mississippi's water quality standards; therefore, for TMDL development, an appropriate target was defined. Oxbow lakes are naturally dynamic systems and have limited life spans, typically filling with sediment over time (Monroe et al, 1992). As a result, a reasonable goal for TMDL development is not necessarily to prevent sediment accumulation entirely, but to return the lake to its natural rate of sediment accumulation. Therefore, a target sedimentation rate was defined based on an assessment of current watershed sediment loading rates and sediment loading rates under various land management conditions. The land management scenarios used to develop the target sedimentation rates include only a few examples of how the current land uses could be modified to reduce the sediment loading. Other options, beyond those presented in this report are possible.

5.1.2 Organic Enrichment/Low DO and Nutrients

The endpoint for organic enrichment/low DO and nutrient TMDL development for Bee Lake is based on the daily average of not less than 5.0 mg/L.

Generally, an organic enrichment/low DO impairment suggests critical conditions in the water body that result from processes that link sources of nutrients and organic material to biological processes and DO levels.

For this TMDL, organic enrichment has been expressed in terms of total biochemical oxygen demand (TBODu). TBODu represents the oxygen consumed by microorganisms while stabilizing or degrading carbonaceous and nitrogenous compounds under aerobic conditions over an extended time period. The carbonaceous compounds are referred to as CBODu and the nitrogenous compounds are referred to as NBODu. TBODu is equal to the sum of CBODu and TBODu.

$$TBODu = CBODu + NBODu \qquad [1]$$

The watershed model gives an estimate of oxygen-consuming substances from which an estimate of the TBODu has been made. The CBODu load can be estimated from the stoichiometric relationship between the total organic carbon (TOC) and oxygen, which is 2.67 pounds of oxygen per pound of carbon consumed (Thomann and Mueller, 1987). Since the watershed model does not directly simulate TOC, an indirect estimate of TOC can be made based on the stoichiometric equivalent between organic matter (OM) and carbon. OM can be converted to TOC using a stoichiometric relationship, which is 0.45 times the OM (Cole and Buchak, 1995). Thus, the CBODu can then be determined from the OM by multiplying it by (0.45 x 2.67) or a factor of 1.2.

To convert the ammonia nitrogen (NH_3-N) loads to an oxygen demand, a factor of 4.57 pounds of oxygen per pound of ammonia nitrogen (NH_3-N) oxidized to nitrate nitrogen (NO_3-N) was used (USEPA, 1993). Using this factor is a conservative modeling assumption because it assumes that all the ammonia is converted to nitrate through nitrification, which is not necessarily accurate. The oxygen demand caused by nitrification of ammonia is equal to the NBODu load. Thus, TBODu can be estimated using the revised equation [1] given below:

$$TBODu = 1.2\ OM + 4.57\ NH_3\text{-}N \qquad [2]$$

5.2 Critical Condition and Seasonality

40 CFR Section 130 require TMDLs to consider critical environmental conditions and seasonal environmental variations. The requirements are designed to simultaneously ensure that water quality is protected during times when it is most vulnerable and take into account changes in streamflow and loading characteristics as a result of hydrological or climatological variations. These conditions are important because they describe the factors that combine to cause violations of water quality standards and can help identify necessary remedial actions.

5.2.1 Sediment/Siltation

The sediment analysis considered seasonality in the loading through the simulation of monthly watershed loadings based on historic precipitation records. The evaluation of sediment impacts in the lake was considered for the average annual conditions representing the response to long-term, cumulative siltation. The TMDL and load allocation are presented as an annual average loading consistent with the type of impairment (siltation) and water body type (oxbow lake). Reduction of the average annual load is needed to meet water quality standards.

The critical conditions for the sediment TMDL are selected to evaluate the type of impairment (siltation) and the type of water body (oxbow lake). Protection of the lake condition requires the control of long-term loadings and accumulation of sediment. The lake condition is evaluated based on mean siltation rates, in selected locations, in response to long-term annual loading and trapping of sediments in the lake.

5.2.2 Organic Enrichment/Low DO and Nutrients

The organic enrichment/low DO and nutrients analysis considered seasonality in the loading through the simulation of monthly watershed loadings based on historic precipitation records. Long-term simulation of the lake model under varying precipitation and meteorological conditions takes the seasonality into account.

Historic precipitation values for a period of 15 years were evaluated from 1985 to 2000 (Figure 5-1) at the Yazoo City precipitation station (see Figure B-3 in Appendix B for the location of the Yazoo City station). The years 1997 to 2000 were chosen as the TMDL simulation period as these years were not extreme and were close to the annual average precipitation. This period had a wet year in 1997 and a dry year in 2000 (Figure 5-1). Extreme years (very dry or very wet) were not considered for the TMDL. Also, the period from 1997 through 2000 corresponded to the years where the most complete data set of hourly surface airways meteorological data was available from the Jackson, Mississippi, surface airways station (Figure B-3).

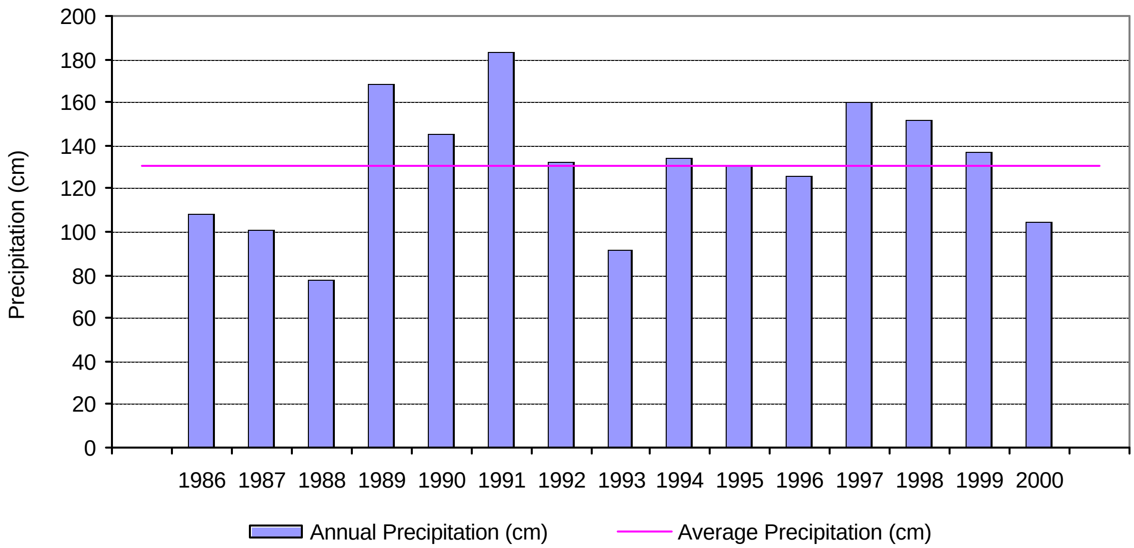

Figure 5-1. Historic Precipitation, 1985 – 2000 (Yazoo City).

Simulation results from the inlake model for this period showed that 1997 was the critical period and meeting the MDEQ DO criteria during this period would be used to determine the TMDL. As shown in Figure 5-2, the simulation period exhibited a wide range of hydrologic conditions with wet a spring and dry summer. Lakes are also typically conducive to eutrophication under these conditions. It can be noted that these years have some relatively dry summer months as well.

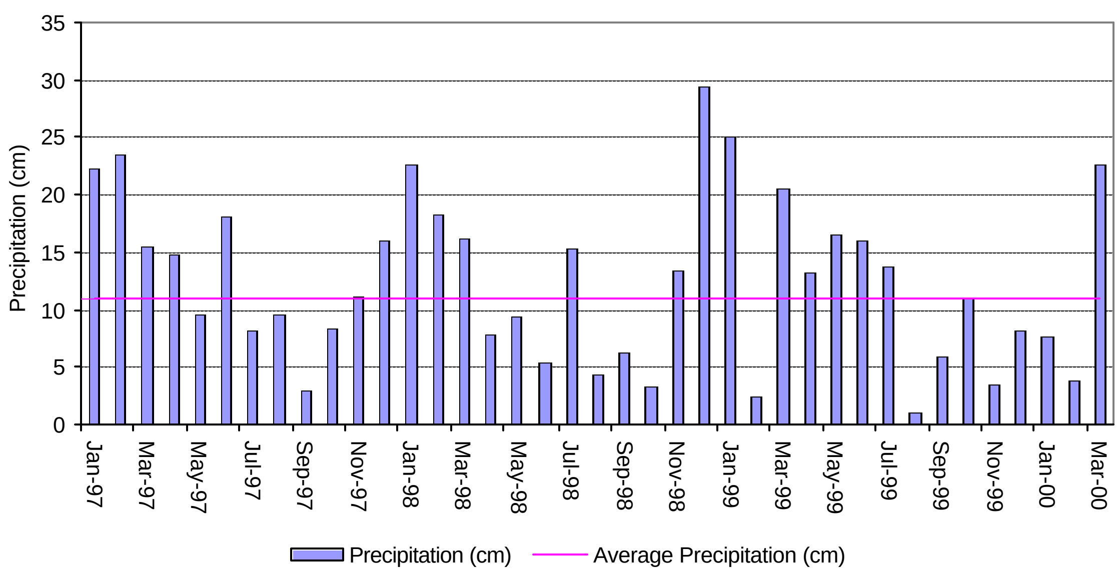

Figure 5-2. Monthly Precipitation 1997-2000 (Yazoo City)

5.3 Sediment Loading Analysis

The sediment loading analysis was based on the long-term average sedimentation rate. Table A-6 in Appendix A provides the computed mean sedimentation rate of the lake for six possible land management scenarios: (1) existing condition (moderate tillage), (2) conventional tillage, (3) 50 percent wooded and moderate tillage, (4) no tillage, (5) 50 percent wooded and no tillage, and (6) 100 percent wooded. The estimated life span of the lake under these six conditions is presented in Figure 5-3.

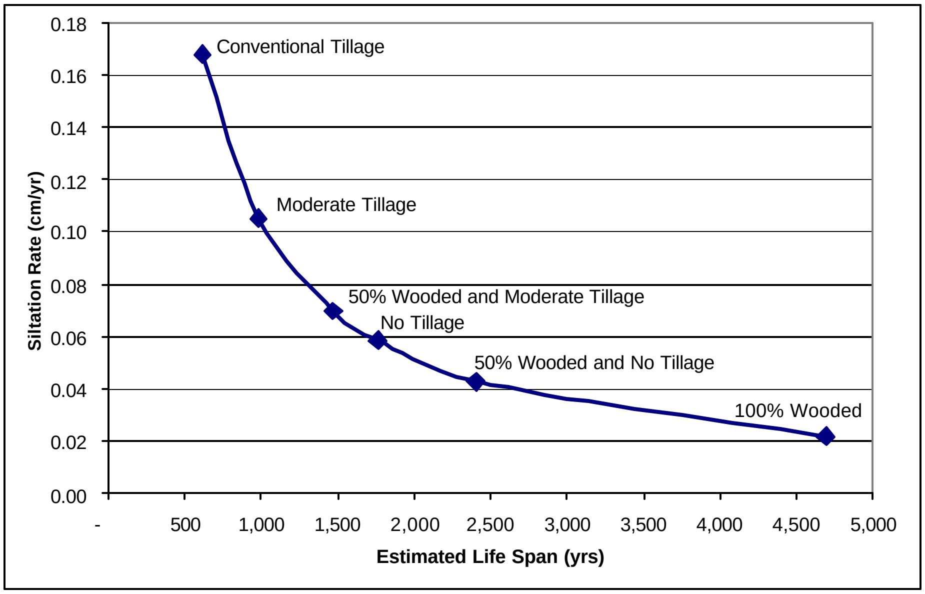

Figure 5-3. Estimated Life Span for Scenarios

These scenarios are based on example land management practices that would result in varying life spans for the lake. The target range was selected in order to achieve a reasonable improvement in sedimentation rates. A range of rates from 0.07 cm/year to 0.04 cm/year was identified as a long-term average sedimentation endpoint. While this range corresponds to the scenarios of 50 percent wooded and moderate tillage to 50 percent wooded and no tillage, this TMDL is not requiring that these particular BMPs be implemented in the watershed. The reductions can be achieved through various combinations of BMPs that could reasonably be put in place in the Bee Lake watershed. This TMDL encourages the use of land management practices, including planting additional forested area and using conservative tillage practices in agricultural areas. As shown in Figure 5-3, the use of these land management practices will significantly extend the life span of Bee Lake.

5.4 TMDL Allocations of Sediment

According to the model, a sedimentation rate of 0.07 cm/year occurred when the sediment load from the watershed was reduced by 33 percent. A sediment load reduction of 60 percent gave an estimated sedimentation rate of 0.04 cm/year. This range of sedimentation rates is estimated to extend the life span of the lake from approximately 980 years under existing conditions to between 1,400 and 2,400 years.

This reduction was distributed among the different land use categories in the watershed, based on load reduction feasibility (Tables 5-1 and 5-2). No reduction was applied to the "other" land use category, which was considered a background (non-anthropogenic) land use. The "other" land use category consists of bottomland hardwood forests, shrubs, woods, and swamp. Additionally no reduction was applied to the "residential" land use category since residential land use in the Bee Lake watershed was negligible and comprised of less than 1 percent of the total land use in the watershed. Although the sediment load from the "Aquaculture" category is small, it was reduced because its contribution was significant in terms of oxygen-demanding substances.

Table 5-1. Load Reduction Scenario - Sedimentation Rate of 0.07 cm/year

LAND USE	BASELINE (ton/yr)	REDUCTION (ton/yr)	REDUCTION (%)
Agriculture Cultivated	4,770	1,685	35
Agriculture Noncultivated	331	117	35
Aquaculture	2	0	0
Residential	28	0	0
Other	216	0	0
Total	**5,347**	**1,802**	33

Table 5-2. Load Reduction Scenario - Sedimentation Rate of 0.04 cm/year

LAND USE	BASELINE (ton/yr)	REDUCTION (ton/yr)	REDUCTION (%)
Agriculture Cultivated	4,770	2,987	63
Agriculture Noncultivated	331	207	63
Aquaculture	2	0	0
Residential	28	0	0
Other	216	0	0
Total	**5,347**	**3,194**	60

The TMDLs for the selected range of sedimentation rates are presented in Tables 5-3 and 5-4. Based on the model, the sediment load to achieve a sedimentation rate of 0.07 cm/year is 0.33 ton/acre/year, and the sediment load to achieve a sedimentation rate of 0.04 cm/year is approximately 0.20 ton/acre/year. It should be stressed that these numbers are only approximations, based on an interpretation of the limited data available for Bee Lake. There were many assumptions and limitations used in calculating these loads. Collection of additional data or the consideration of other land use management scenarios may result in refinement or modifications of the TMDLs.

Table 5-3. TMDL for Sedimentation Rate of 0.07 cm/year for Bee Lake

Pollutant	WLA (ton/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.33	0.33	Implicit	0.33

Table 5-4. TMDL for Sedimentation Rate of 0.04 cm/year for Bee Lake

Pollutant	WLA (ton/acre/year)	LA (ton/acre/year)	MOS (ton/acre/year)	TMDL (ton/acre/year)
Sediment	0.20	0.20	Implicit	0.20

5.5 TMDL Allocations of TBODu

No reduction in the annual watershed loading is recommended to achieve the inlake DO criteria. The percent contribution of $TBOD_u$ is distributed among the different land use categories in the watershed (Table 5-5).

Table 5-5. Percent Contribution of TBODu

	BASELINE	
LAND USE	**NBODu (lb/day)**	**CBODu (lb/day)**
Agriculture cultivated	65	116
Agriculture noncultivated	13.1	21.1
Aquaculture	0.2	0.2
Other	5.2	9.1
Residential	1.5	2.5
Total	**85**	**149**

Based on the baseline loads, the TBODu was computed using equation [2] described in Section 5.1.2, and the TMDL is presented in Table 5-6. The TMDL for TBODu was computed to be approximately 234 lb/day.

Table 5-6. TMDL for TBODu for Bee Lake

Pollutant	WLA (lb/day)	LA (lb/day)	MOS (lb/day)	TMDL (lb/day)
CBODu	0	149	Implicit	149
NBODu	0	85	Implicit	85
TBODu	0	234	Implicit	234

5.6 Margin of Safety

The MOS is one of the required elements of a TMDL. There are two basic methods for incorporating the MOS (USEPA, 1991):

- Implicitly incorporate the MOS using conservative model assumptions to develop allocations.
- Explicitly specify a portion of the total TMDL as the MOS; use the remainder for allocations.

The margin of safety for this TMDL was expressed implicitly through implicit conservative assumptions that provide a margin of safety. Specific conservative assumptions include:

- The loadings calculated by the nonpoint source model (GWLF) were derived using conservative assumptions in the selection of nutrient potency and sediment loading factors.
- The use of conservative assumptions in developing the loading model results in relatively high loads and slightly larger required load reductions.

5.7 Reasonable Assurance

This component of TMDL development does not apply. There are no point sources requesting a reduction based on LA components and reductions.

5.8 Public Participation

This TMDL will be published for a 30-day public notice period. During this time, the public will be notified by publication in the statewide newspaper. The public will be given an opportunity to review the TMDL and submit comments. MDEQ also distributes all TMDLs at the beginning of the public notice period to those members of the public who have requested to be included on a TMDL mailing list. TMDL mailing list members may ask to receive the TMDL reports through either, email or the postal service. Anyone wishing to be included on the TMDL mailing list should contact Greg Jackson at (601) 961-5098 or Greg_Jackson@deq.state.ms.us.

All comments received during the public notice period and at any public hearings become a part of the record of this TMDL. All comments will be considered in the submission of this TMDL to EPA Region 4 for final approval.

5.9 Future Monitoring

MDEQ has adopted the Basin Approach to Water Quality Management, a plan that divides Mississippi's major drainage basins into five groups. During each yearlong cycle, MDEQ's resources for water quality monitoring will be focused on one of the basin groups. During the next monitoring phase in the Yazoo Basin, Bee Lake may undergo additional monitoring to identify any change in water quality. The additional monitoring may allow refinements of the assumptions used to calculate this TMDL.

5.10 Conclusion

To evaluate the relationship between the sources, their loading characteristics, and the resulting conditions in the lake, a combination of analytical tools was used. This involved a source response linkage between the GWLF watershed model for the Bee Lake watershed and a 2-dimensional inlake water quality model CE-QUAL-W2 for Bee Lake. The sediment load estimates from the GWLF model were used in the sedimentation rate analysis for the lake. The sedimentation rate analysis was based on a long-term average sedimentation rate that assessed a range of land management practices. A range of 0.07 cm/year to 0.04 cm/year was identified as a long-term average sedimentation endpoint based on the example land management scenarios included in this TMDL.

No reduction in the oxygen-demanding source loadings coming from the watershed is needed to meet the prescribed DO criteria of a daily average of 5 mg/L. However, it is recommended that additional loading, including NPDES-permitted sources, not be allowed in the lake in the future. A 33 to 60 percent reduction of sediment load was also recommended to address the siltation loading. The sediment TMDL was computed to be approximately 0.33 ton/acre/year to 0.20 ton/acre/year of sediment for the range of selected endpoints. The organic enrichment/low DO TMDL for TBODu was computed to be approximately 234 lb/day.

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Definitions

Ammonia: Inorganic form of nitrogen (NH_3); product of hydrolysis of organic nitrogen and denitrification. Ammonia is preferentially used by phytoplankton over nitrate for uptake of inorganic nitrogen.

Ammonia Nitrogen: The measured ammonia concentration reported in terms of equivalent ammonia concentration; also called total ammonia as nitrogen (NH_3-N)

Ammonia Toxicity: Under specific conditions of temperature and pH, the un-ionized component of ammonia can be toxic to aquatic life. The un-ionized component of ammonia increases with pH and temperature.

Ambient Stations: A network of fixed monitoring stations established for systematic water quality sampling at regular intervals, and for uniform parametric coverage over a long-term period.

Assimilative Capacity: The capacity of a body of water or soil-plant system to receive wastewater effluents or sludge without violating the provisions of the State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters and Water Quality regulations.

Background: The condition of waters in the absence of man-induced alterations based on the best scientific information available to MDEQ. The establishment of natural background for an altered water body may be based upon a similar, unaltered or least impaired, water body or on historical pre-alteration data.

Biological Impairment: Condition in which at least one biological assemblage (e.g., fish, macroinvertabrates, or algae) indicates less than full support with moderate to severe modification of biological community noted.

Carbonaceous Biochemical Oxygen Demand: Also called CBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous compounds under aerobic conditions over an extended time period.

Calibrated Model: A model in which reaction rates and inputs are significantly based on actual measurements using data from surveys on the receiving water body.

Critical Condition: Hydrologic and atmospheric conditions in which the pollutants causing impairment of a water body have their greatest potential for adverse effects.

Daily Discharge: The "discharge of a pollutant" measured during a calendar day or any 24-hour period that reasonably represents the calendar day for the purposes of sampling. For pollutants with limitations expressed in units of mass, the daily discharge is calculated as the total mass of the pollutant discharged over the day. For pollutants with limitations expressed in other units of measurement, the daily average is calculated as the average.

Designated Use: Use specified in water quality standards for each water body or segment regardless of actual attainment.

Discharge Monitoring Report: Report of effluent characteristics submitted by an NPDES-permitted facility.

Dissolved Oxygen: The amount of oxygen dissolved in water. It also refers to a measure of the amount of oxygen that is available for biochemical activity in a water body. The maximum concentration of dissolved oxygen in a water body depends on temperature, atmospheric pressure, and dissolved solids.

Dissolved Oxygen Deficit: The saturation dissolved oxygen concentration minus the actual dissolved oxygen concentration.

DO Sag: Longitudinal variation of dissolved oxygen representing the oxygen depletion and recovery following a waste load discharge into a receiving water.

Effluent Standards and Limitations: All state or federal effluent standards and limitations on quantities, rates, and concentrations of chemical, physical, biological, and other constituents to which a waste or wastewater discharge may be subject under the federal act or the state law. This includes, but is not limited to, effluent limitations, standards of performance, toxic effluent standards and prohibitions, pretreatment standards, and schedules of compliance.

Effluent: Treated wastewater flowing out of the treatment facilities.

First Order Kinetics: Describes a reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.

5-Day Biochemical Oxygen Demand: Also called BOD5, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over a period of 5 days.

Groundwater: Subsurface water in the zone of saturation. Groundwater infiltration describes the rate and amount of movement of water from a saturated formation.

Impaired Water body: Any water body that does not attain water quality standards due to an individual pollutant, multiple pollutants, pollution, or an unknown cause of impairment.

Land Surface Runoff: Water that flows into the receiving stream after application by rainfall or irrigation. It is a transport method for nonpoint source pollution from the land surface to the receiving stream.

Load Allocation (LA): The portion of a receiving water's loading capacity attributed to or assigned to nonpoint sources (NPS) or background sources of a pollutant

Loading: The total amount of pollutants entering a stream from one or multiple sources.

Mass Balance: An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving a defined area; the flux in must equal the flux out.

Nonpoint Source: Pollution contained in runoff from the land. Rainfall, snowmelt, and other water that does not evaporate become surface runoff and either drain into surface waters or soak into the soil and finds their way into groundwater. This surface water may contain pollutants that come from land use activities such as agriculture, construction, silviculture, surface mining, disposal of wastewater, hydrologic modifications, and urban development.

Nitrification: The oxidation of ammonium salts to nitrites via Nitrosomonas bacteria and the further oxidation of nitrite to nitrate via Nitrobacter bacteria.

Nitrogenous Biochemical Oxygen Demand: Also called NBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading nitrogenous compounds under aerobic conditions over an extended time period.

NPDES Permit: An individual or general permit issued by the Mississippi Environmental Quality Permit Board pursuant to regulations adopted by the Mississippi Commission on Environmental Quality under Mississippi Code Annotated (as amended) §§ 49-17-17 and 49-17- 29 for discharges into state waters.

Photosynthesis: The biochemical synthesis of carbohydrate-based organic compounds from water and carbon dioxide using light energy in the presence of chlorophyll.

Point Source: Pollution loads discharged at a specific location from pipes, outfalls, and conveyance channels from either wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving stream.

Pollution: Contamination, or other alteration of the physical, chemical, or biological properties, of any waters of the state, including change in temperature, taste, color, turbidity, or odor of the waters, or such discharge of any liquid, gaseous, solid, radioactive, or other substance, or leaks into any waters of the state, unless in compliance with a valid permit issued by the Permit Board.

Publicly Owned Treatment Works (POTW): A waste treatment facility owned and/or operated by a public body or a privately owned treatment works, which accepts discharges, which would otherwise be subject to Federal Pretreatment Requirements.

Reaeration: The net flux of oxygen occurring from the atmosphere to a body of water across the water surface.

Regression Coefficient: An expression of the functional relationship between two correlated variables that is often empirically determined from data, and is used to predict values of one variable when given values of the other variable.

Respiration: The biochemical process by means of which cellular fuels are oxidized with the aid of oxygen to permit the release of energy required to sustain life. During respiration, oxygen is consumed and carbon dioxide is released.

Sediment Oxygen Demand: The solids discharged to a receiving water are partly organics, which upon settling to the bottom decompose aerobically, removing oxygen from the surrounding water column.

Storm Runoff: Rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate slower than rainfall intensity, but instead flows into adjacent land or water bodies or is routed into a drain or sewer system.

Streeter-Phelps DO Sag Equation: An equation, which uses a mass balance approach to determine the DO concentration in a water body downstream of a point source discharge. The equation assumes that the stream flow is constant and that CBODu exertion is the only source of DO deficit while reaeration is the only sink of DO deficit.

Total Ultimate Biochemical Oxygen Demand: Also called TBODu, the amount of oxygen consumed by microorganisms while stabilizing or degrading carbonaceous or nitrogenous compounds under aerobic conditions over an extended time period.

Total Kjeldahl Nitrogen: Also called TKN, organic nitrogen plus ammonia nitrogen.

Total Maximum Daily Load or TMDL: The calculated maximum permissible pollutant loading to a water body at which water quality standards can be maintained.

Waste: Sewage, industrial wastes, oil field wastes, and all other liquid, gaseous, solid, radioactive, or other substances that may pollute or tend to pollute any waters of the State.

Waste load Allocation (WLA): The portion of a receiving waters loading capacity attributed to or assigned to point sources of a pollutant.

Water Quality Standards: The criteria and requirements set forth in State of Mississippi Water Quality Criteria for Intrastate, Interstate, and Coastal Waters. Water quality standards are standards composed of designated present and future most beneficial uses (classification of waters), the numerical and narrative criteria applied to the specific water uses or classification, and the Mississippi antidegradation policy.

Water Quality Criteria: Elements of state water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports the present and future most beneficial uses.

Waters of the State: All waters within the jurisdiction of this state, including all streams, lakes, ponds, wetlands, impounding reservoirs, marshes, watercourses, waterways, wells, springs, irrigation systems, drainage systems, and all other bodies or accumulations of water, surface and underground, natural or artificial, situated wholly or partly within or bordering upon the state, and such coastal waters as are within the jurisdiction of the state, except lakes, ponds, or other surface waters which are wholly landlocked and privately owned, and which are not regulated under the Federal Clean Water Act (33 U.S.C.1251 et seq.).

Watershed: The area of land draining into a stream at a given location.

Abbreviations

BASINS.....................Better Assessment Science Integrating Point and Nonpoint Sources
BMP .... Best Management Practice
$CBOD_5$ .... 5-Day Carbonaceous Biochemical Oxygen Demand
$CBOD_U$... Carbonaceous Ultimate Biochemical Oxygen Demand
CWA .... Clean Water Act
DMR..Discharge Monitoring Report
US EPA ....U.S. Environmental Protection Agency
GIS ....Geographic Information System
HUC .... Hydrologic Unit Code
LA...Load Allocation
MARIS .... Mississippi Automated Resource Information System
MDEQ.. Mississippi Department of Environmental Quality
MGD... Million Gallons per Day
MOS...Margin of Safety
$NBOD_U$.. Nitrogenous Ultimate Biochemical Oxygen Demand
NH_3...Total Ammonia
NH_3-N.. Total Ammonia as Nitrogen
NO_2+ NO_3 ....Nitrite Plus Nitrate
NPDES ....National Pollutant Discharge Elimination System
RBA.. Rapid Biological Assessment
7Q10..............7-Day Average Low Stream Flow with a 10-Year Occurrence Period
$TBOD_5$.. 5-Day Total Biochemical Oxygen Demand
$TBOD_u$ .... Total Ultimate Biochemical Oxygen Demand
TKN...Total Kjeldahl Nitrogen
TN...Total Nitrogen
TOC.. Total Organic Carbon
TP .... Total Phosphorus
USGS... United States Geological Survey
WLA...Waste Load Allocation

APPENDIX A

Watershed model and Siltation Analysis for Bee Lake Watershed

1.0 Model Selection

The Generalized Watershed Loading Function (GWLF) model was selected to estimate sediment and oxygen-demanding substance loadings to Bee Lake. Key characteristics of the GWLF model include the following:

- Limited data requirements
- Sediment simulation using the standard USLE method
- Hydrology simulation using the Curve Number method
- Capable of representing heterogeneous land uses

The sediment loads, from all land uses except aquaculture (catfish ponds) were generated using the GWLF model for the Bee Lake watershed. The catfish pond sediment load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in sediment concentrations. The GWLF model loads and catfish pond sediment loads were applied to a siltation and life span analysis for assessment of sediment/siltation impairments.

The nutrient loads from all land uses except catfish ponds were generated using the GWLF model for the Bee Lake watershed. The catfish pond nutrient load was simulated outside of the GWLF model to account for pond management practices and seasonal variation in nutrient concentrations. The GWLF model loads and catfish pond nutrient loads were applied to CEQUAL, a separate receiving water model, for assessment of the organic enrichment/low dissolved oxygen (DO) and nutrient impairments.

2.0 Model Framework

The GWLF model, which was originally developed by Cornell University (Haith and Shoemaker, 1987; Haith et al., 1992), provides the ability to simulate runoff, sediment, and nutrient loadings from watersheds given variable-size source areas (e.g., agricultural, forested, and developed land). It also has algorithms for calculating septic system loads and allows for the inclusion of point source discharge data. GWLF is a continuous simulation model that uses daily time steps for weather data and water balance calculations. Monthly calculations are made for sediment and nutrient loads, based on daily water balance totals that are summed to give monthly values.

GWLF is an aggregate distributed/lumped parameter watershed model. For surface loading, it is distributed in the sense that it allows multiple land use and cover scenarios. Each area is assumed to be homogeneous with respect to various attributes considered by the model. Additionally, the model does not spatially distribute the source areas, but aggregates the loads from each area into a watershed total. In other words, there is no spatial routing. For subsurface loading, the model acts as a lumped parameter model using a water balance approach. No distinctly separate areas are considered for subsurface flow contributions. Daily water balances are computed for an unsaturated zone as well as for a saturated subsurface zone, where infiltration is computed as the difference between precipitation and snowmelt minus surface runoff and evapotranspiration.

GWLF models surface runoff using the Soil Conservation Service Curve Number (SCS-CN) approach with local daily weather (temperature and precipitation) inputs. Erosion and sediment yield are estimated using monthly erosion calculations based on the Universal Soil Loss Equation (USLE) algorithm (with monthly rainfall-runoff coefficients) and a monthly composite of KLSCP values for each source area (e.g., land cover/soil type combination). The KLSCP factors are variables used in the calculations to depict changes in soil loss/erosion (K), the length/slope factor (LS), the vegetation cover factor (C), and the conservation practices factor (P). The USLE approach is commonly used to predict erosion, particularly in agricultural areas, and it is a component of other watershed models such as the Agricultural Non Point Source Loading model (AGNPS) and the Soil and Water Assessment Tool (SWAT). A sediment delivery ratio (SDR), based on watershed size, and a transport capacity, based on average daily runoff, are applied to the calculated erosion to determine sediment yield for each source area.

Surface nutrient losses are determined by applying dissolved nitrogen and phosphorus coefficients to surface runoff and a sediment coefficient to the yield portion for each agricultural source area. Point source discharges, which are not of concern in this study area, can also contribute to dissolved loads to the stream and are specified in terms of kilograms per month. Manured areas, as well as septic systems, can also be considered. Urban nutrient inputs are all assumed to be solid phase, and the model uses an exponential accumulation and wash off function for these loadings. Subsurface losses are calculated using dissolved nitrogen and phosphorus coefficients for shallow groundwater contributions to stream nutrient loads, and the subsurface submodel considers only a single, lumped-parameter contributing area.

Evapotranspiration is determined using daily weather data and a cover factor dependent on land use and land cover type. A water balance is performed daily using supplied or computed precipitation, snowmelt, initial unsaturated zone storage, maximum available zone storage, and evapotranspiration values. All the equations used by the model can be found in the original GWLF paper (Haith and Shoemaker, 1987) and GWLF User's Manual (Haith et al., 1992).

3.0 Model Configuration

Watershed data needed to run the GWLF model with the BasinSim 1.0 interface were generated using geographic information system (GIS) spatial coverages, local weather data, literature values, and other information. For execution, the model requires three separate input files containing transport parameters, nutrient parameters, and weather-related data.

More detailed information about these parameters and other secondary parameters can be obtained from the GWLF User's Manual (Haith et al., 1992). Pages 15 through 41 of the manual provide specific details that describe equations and typical parameter values used in the model.

3.1 Transport Parameters

The transport file (TRANSPRT.DAT) defines parameters that are a function of hydrology, erosion, and sedimentation. These parameters include global transport parameters, seasonal transport parameters, and source area transport parameters.

3.1.1 Source Area Transport Parameters

Model inputs for the source area transport parameters are shown in Figure A-1. These parameters account for the spatial variation in hydrology, erosion, and sedimentation. They include land use area, curve number, and the Universal Soil Loss (USLE) parameters K, LS, C, and P.

Land Use Type	Area (ha)	CN	K*LS*C*P
Corn	10	80	0.0136
Cotton	2,288	82	0.0234
Other Small Grains	11	80	0.0084
Rice	27	80	0.0084
Snap Beans	17	80	0.0234
Sorghum	14	81	0.0192
Soybeans	76	82	0.0234
Sunflowers	9	80	0.0195
Winter Wheat	12	80	0.0084
Pasture/Range/Non-Agriculture	691	75	0.0057
Aquaculture	32	100	0.0000
Bottomland Hardwood Forest	705	71	0.0030
Freshwater	203	100	0.0000
Freshwater Scrub/Shrub	22	72	0.0030
Riverine Swamp	47	70	0.0030
Upland Scrub/Shrub	3	70	0.0030
Woods	81	71	0.0030
Urban Pervious	63	77	0.0053
Urban Impervious	7	98	0.0000

Figure A-1. Land Use Parameters

The watershed boundary was delineated using a 10-meter Digital Elevation Map (DEM), and USGS 7.5-minute digital topographic maps (24K DRG–Digital Raster Graphics).

The land use and land cover percentages were derived from a data layer developed as part of the Mississippi Land Cover Project (MDEQ, 1997) and the 2001 cropland data layer developed by the National Agricultural Statistics Service (USDA, 2001). The l9 land uses used for model simulation were grouped into five categories for model result presentation (Table A-1).

Table A-1. Land Use Categories

Category	Land Use/Land Cover	Area (ha)	Area (% of Total)
Cultivated Agriculture	Cotton, Corn, Soybean, Sorghum, Snap Beans, Other Small Grains, Rice, Winter Wheat, Sunflower	2,465	57%
Noncultivated Agriculture	Pasture, Range, Fallow	691	16%
Catfish Ponds	Catfish Ponds	32	1%
Residential	Pervious Residential, Impervious Residential	70	1%
Other	Bottomland Hardwood Forest, Riverine Swamp, Upland Scrub, Woods, Freshwater Scrub, Open Water	1,061	25%

The curve number parameter determines the amount of precipitation that infiltrates into the ground or enters surface water as runoff. It is based on specified combinations of land use/cover and hydrologic soil type and is calculated directly using digital land use and soils coverages.

Soils data were obtained from Mississippi county soil surveys and the State Soil Geographic (STATSGO) database for Mississippi, as developed by the Natural Resources Conservation Service (NRCS).

The USLE equation determines soil erodibility based on the K factor, LS factor, C factor, and P factor. Unless otherwise specified, these parameters are derived from the NRCS Natural Resources Inventory (NRI) database (1992). The individual parameters are described below.

- *K factor:* This relates to inherent soil erodibility, and it affects the amount of soil erosion taking place on a given unit of land. K factor values were derived from STATSGO for the each soil type and assigned to land use areas based on the distribution of soils within that land use area.

- *LS factor:* This is a function of the length and grade of the slope from a source area to the waterbody. An average grade of 0.5 percent was used for the entire watershed based on the 10-meter DEM coverage. The slope length was derived from regional crop-specific literature values from the NRCS NRI database (1992).

- *C factor:* This is related to the amount of vegetative cover in an area and is largely controlled by the crops grown and the cultivation practices used. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion. The C factor was derived from crop-specific literature values from the NRCS NRI database (1992) based on moderate tillage practices.

- *P factor:* This is directly related to the conservation practices used in agricultural areas. Values range from 0 to 1.0, with larger values indicating a lower potential for erosion.

3.1.2 Seasonal Transport Parameters

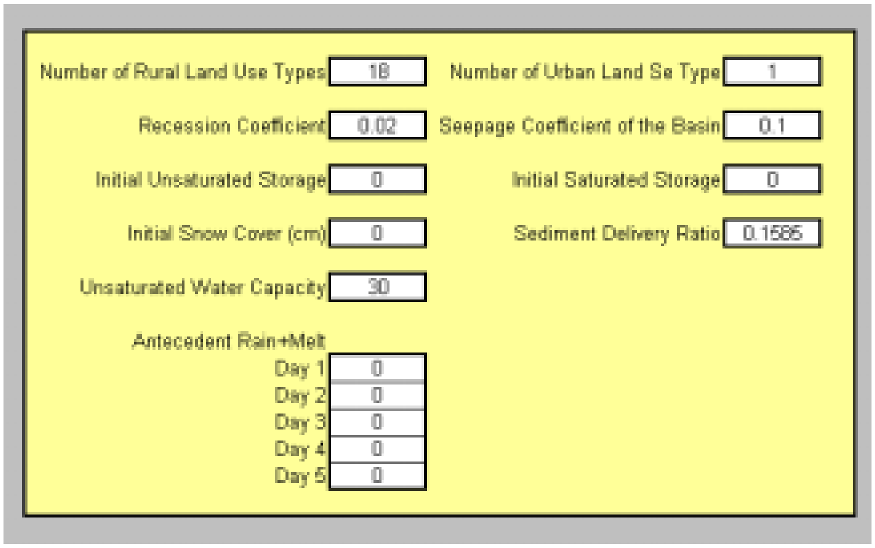
Model inputs for the seasonal transport parameters are shown in Figure A-2. These parameters account for seasonal variability in hydrology, erosion, and sedimentation. The monthly evapotranspiration cover coefficient, day length, and erosivity coefficient are based on regional literature values (Haith et al., 1992).

Month	ET Cover Coef.	Day Length (hrs)	Growing Season	Erosivity Coef.
Apr	0.99	12.8	1	0.2
May	0.99	13.7	1	0.2
Jun	0.99	14.2	1	0.2
Jul	0.99	14	1	0.2
Aug	0.99	13.2	1	0.2
Sep	0.99	12.2	1	0.2
Oct	0.99	11.2	1	0.2
Nov	0.70	10.2	0	0.11
Dec	0.70	9.8	0	0.11
Jan	0.70	10	0	0.11
Feb	0.70	10.8	0	0.11
Mar	0.70	11.8	0	0.11

Figure A-2. Seasonal Transport Parameters

3.1.3 Global Transport Parameters

Model inputs for the global parameters are shown in Figure A-3. Critical global parameters include the unsaturated water capacity, seepage coefficient, recession coefficient, and sediment delivery rate (SDR). The unsaturated water capacity is a function of the maximum watershed rooting depth and the soil available water storage capacity. The seepage coefficient is a function of the loss of water to the deep aquifer. The recession coefficient is a function of the basin's hydrologic response to precipitation event. SDR specifies the percentage of eroded sediment delivered to the surface water and is empirically based on watershed size. These parameters were set within reasonable ranges to match basin characteristics.



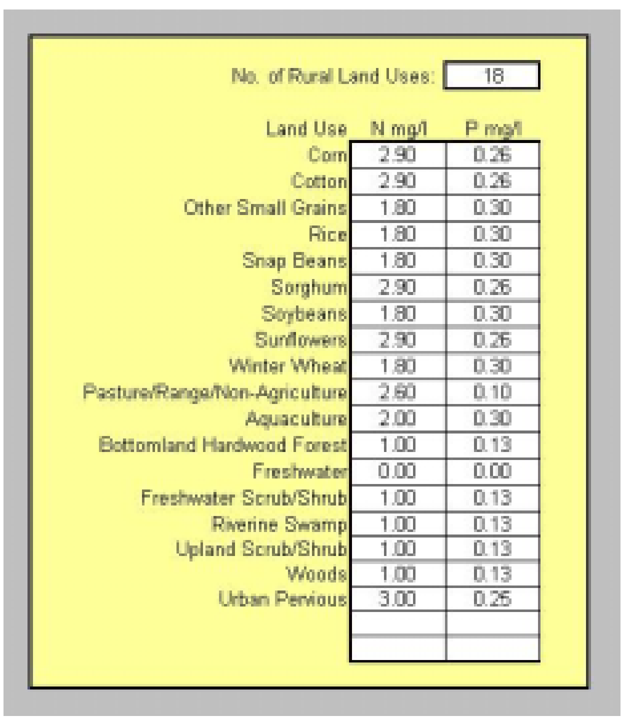
Number of Rural Land Use Types	18	Number of Urban Land Se Type	1
Recession Coefficient	0.02	Seepage Coefficient of the Basin	0.1
Initial Unsaturated Storage	0	Initial Saturated Storage	0
Initial Snow Cover (cm)	0	Sediment Delivery Ratio	0.1585
Unsaturated Water Capacity	30		

Antecedent Rain+Melt	
Day 1	0
Day 2	0
Day 3	0
Day 4	0
Day 5	0

Figure A-3. Global Transport Parameters

3.2 Nutrient Parameters

The nutrient file (NUTRIENT.DAT) specifies the loading parameters for the different sources. The dissolved concentrations for each land use are derived from the literature values for fallow, corn, and small grains and are shown in Figure A-4 (Haith et al., 1992). Soil nitrogen and phosphorus concentrations of 1,000 mg/kg and 880 mg/kg, respectively, and groundwater nitrogen and phosphorus concentrations of 1.08 mg/L and 0.029 mg/L, respectively, were also determined using regional literature values (Haith et al., 1992).



No. of Rural Land Uses: 18

Land Use	N mg/l	P mg/l
Corn	2.90	0.26
Cotton	2.90	0.26
Other Small Grains	1.80	0.30
Rice	1.80	0.30
Snap Beans	1.80	0.30
Sorghum	2.90	0.26
Soybeans	1.80	0.30
Sunflowers	2.90	0.26
Winter Wheat	1.80	0.30
Pasture/Range/Non-Agriculture	2.60	0.10
Aquaculture	2.00	0.30
Bottomland Hardwood Forest	1.00	0.13
Freshwater	0.00	0.00
Freshwater Scrub/Shrub	1.00	0.13
Riverine Swamp	1.00	0.13
Upland Scrub/Shrub	1.00	0.13
Woods	1.00	0.13
Urban Pervious	3.00	0.25

Figure A-4. Dissolved Nitrogen and Phosphorus Concentrations

3.3 Weather Data

The weather file (WEATHER .DAT) contains daily average temperature and total precipitation values for each year simulated. Daily precipitation and temperature data were obtained from local National Climatic Data Center (NCDC) weather stations and are shown in Table A-2 and Figure A-5. The period of record selected for model runs, April 1, 1990 through March 31, 2000, was based on the availability of daily precipitation and temperature data.

Table A-2. Weather Stations

Weather Station	Station Code	Data Type	Data Period
Yazoo City 5 NNE	MS9860	Daily Precip	1960–2000
Jackson International Airport	WBAN 03940	Daily Max/Min Temp	1963-2000

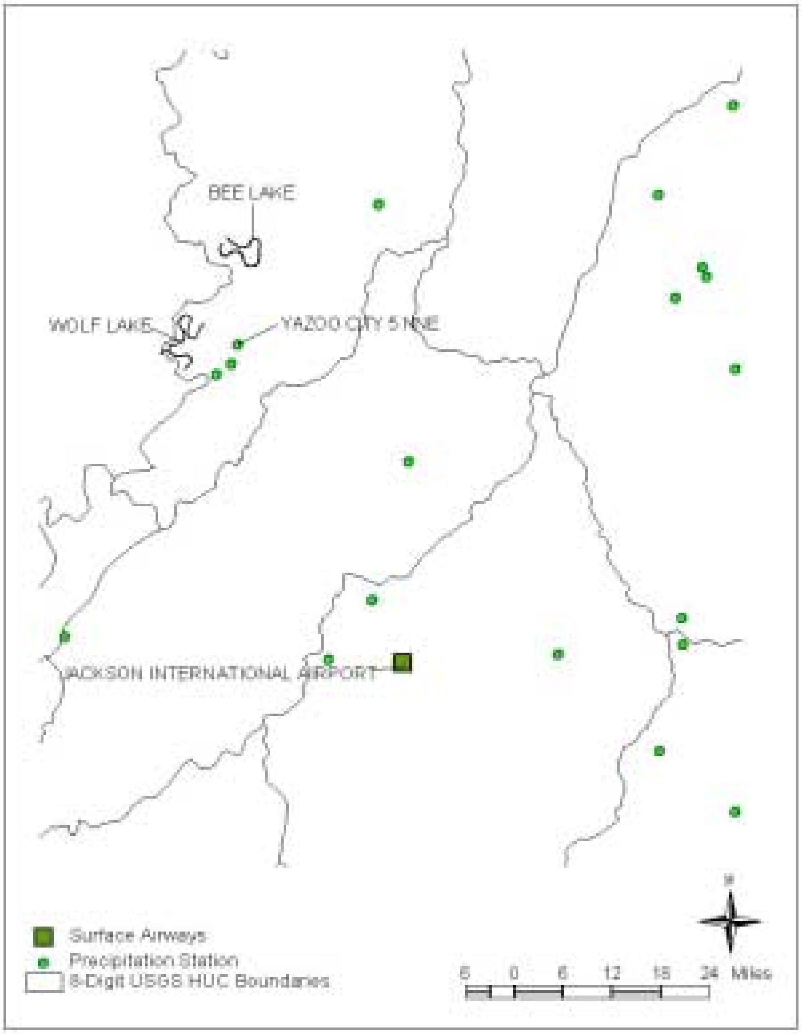


Figure A-5. Precipitation and Temperature Gage Locations

4.0 Watershed Model Calibration

The GWLF model was not calibrated to actual observations, since insufficient data were available. However, local land use, soil, and meteorological data were used to define model parameters and ensure the appropriateness of load estimations. Land management practices including reduced tillage, cover crops, and detention ponds are widely used in the Mississippi Delta (Yuan and Bingner, 2002). Therefore, cover factors used in the USLE method were based on moderate tillage.

5.0 Catfish Pond Analysis

Catfish ponds, representing 80 acres or less than 1 percent of the total watershed area, were simulated outside of GWLF to account for pond management practices and seasonal variations in sediment and nutrient concentrations. Sediment, total nitrogen, and total phosphorus loads were simulated using a spreadsheet tool based on the method described in Tucker et al. 1996. Critical assumptions regarding pond management practices in the Yazoo River Basin incorporated into this analysis include

- Pond surface level is maintained between 7.5 and 15 cm below the top of the drain.
- Food fish ponds represent 90 percent of the total catfish pond area.
- One-sixth of the food fish ponds are drained annually throughout the year.
- Fingerling ponds represent 10 percent of the total catfish pond area, and all the fingerling ponds are drained annually between December and April.
- Broodfish ponds represent a negligible percent of the total catfish pond area.

Catfish pond overflows were predicted from January 1997 to December 2000 on a daily time step based on assumed pond level management practices and daily precipitation, evaporation, and infiltration. The overflow was calculated using the following equation from Tucker et al. 1996, and is shown in Figure A-6.

$$\mathbf{O_d = L_{d-1} - L_d - P_d - 0.8 * E_d - I + GW_d}$$

Where

O_d	= Overflow (cm) on day d
L_{d-1}	= Pond water level (cm) at end of day d-1
L_d	= Pond water level (cm) at end of day d
P_d	= Precipitation (cm) on day d
E_d	= Pan evaporation on day d
I	= Daily infiltration loss (0.04 cm)
GW_d	= Groundwater pumped into pond (cm) on day d

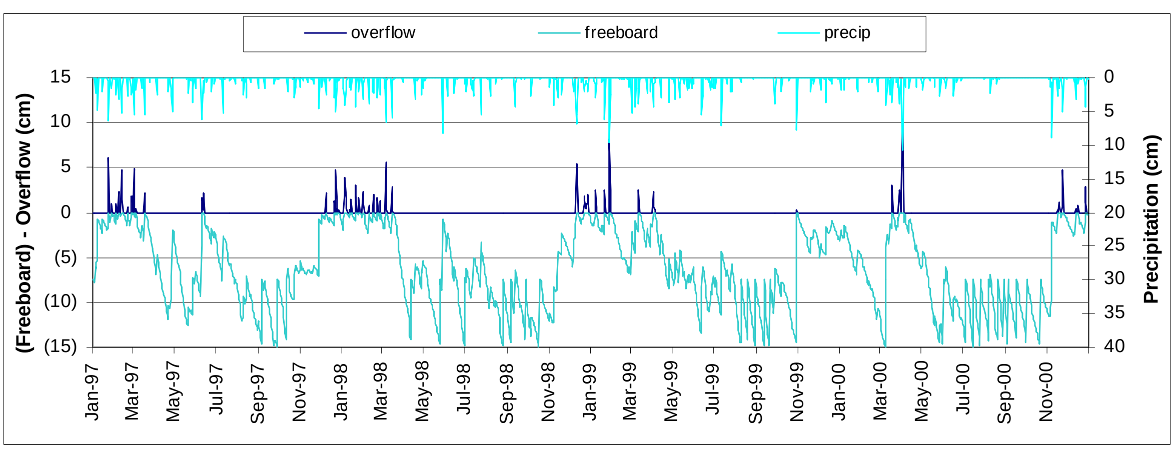


Figure A-6. Predicted Daily Catfish Pond Overflows Jan 1997–Dec 2000

Pond sediment and nutrient loads are predicted on a monthly time step based on average seasonal concentrations, daily overflow water balance totals summed to monthly values, and pond drainage volume assumptions. The predicted seasonal nonvolatile suspended sediment (NVSS), and particulate and soluble phosphorus and nitrogen are shown in Table A-3. NVSS was estimated to be 70 percent of the total suspended solids (Tucker, 2003).

Table A-3. Seasonal NVSS, Total Phosphorus, and Total Nitrogen Concentrations

Season	NVSS (mg/L)	TP (particulate) (mg/L)	TP (soluble) (mg/L)	TN (particulate) (mg/L)	TN (soluble) (mg/L)
Spring	92	0.33	0.02	3.00	1.84
Summer	87	0.47	0.06	5.95	1.17
Autumn	61	0.29	0.02	3.31	3.23
Winter	72	0.33	0.01	3.55	1.76
Mean	78	0.35	0.03	3.95	2.00

Source: Tucker et al, 1996.

The predicted monthly sediment and nutrient loads from January 1997 to December 2000 are shown in Figures A-7 to A-10. The predicted average annual loads from catfish ponds are 2.1 tons sediment, 0.55 tons nitrogen, and 0.01 tons phosphorus. Sediment, nitrogen, and phosphorus loads were highest in the winter months, between November and March, when the highest precipitation occurred and the fingerling ponds were drained. Overflow discharges occurred only rarely outside of the winter months.

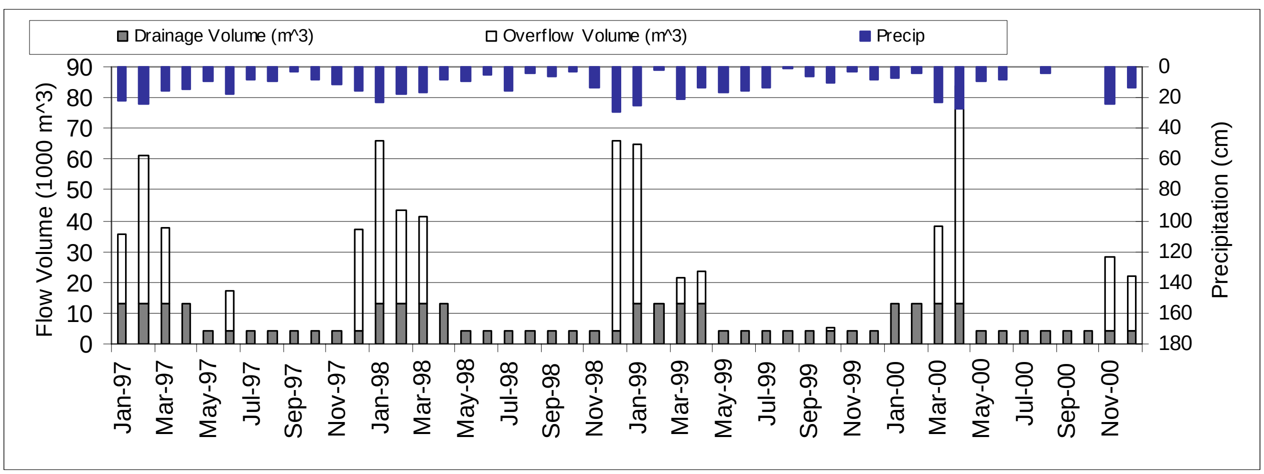


Figure A-7. Monthly Precipitation and Catfish Pond Overflow and Drainage

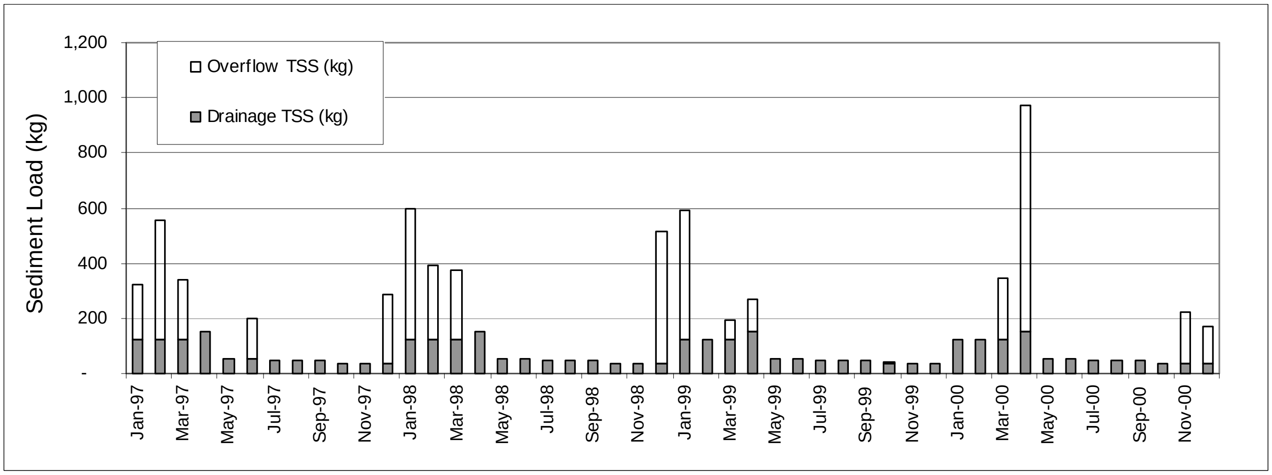


Figure A-8. Monthly Catfish Pond Overflow and Drainage Sediment Load

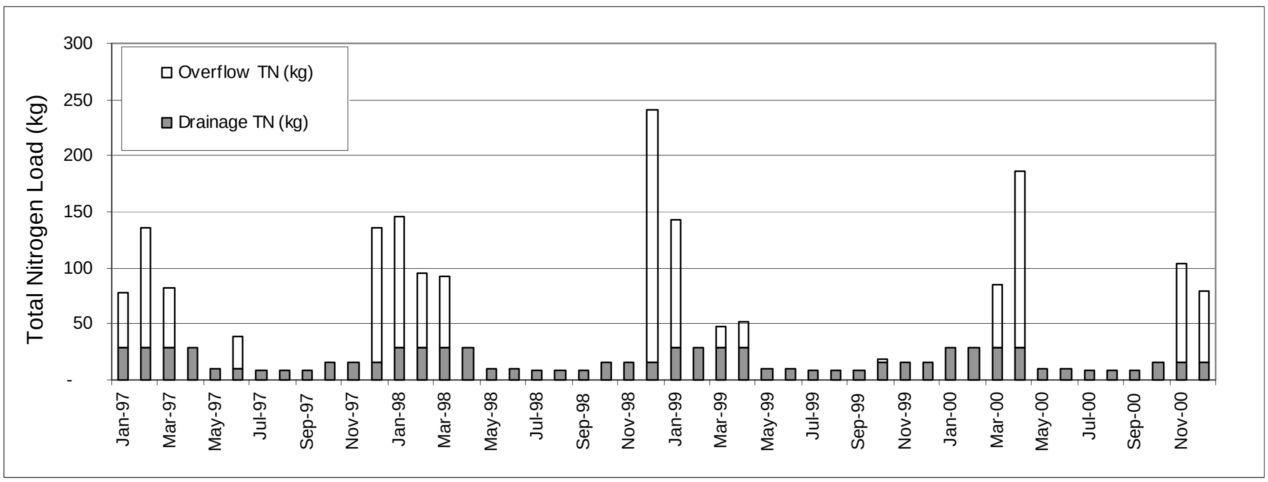


Figure A-9. Monthly Catfish Pond Overflow and Drainage Nitrogen Load

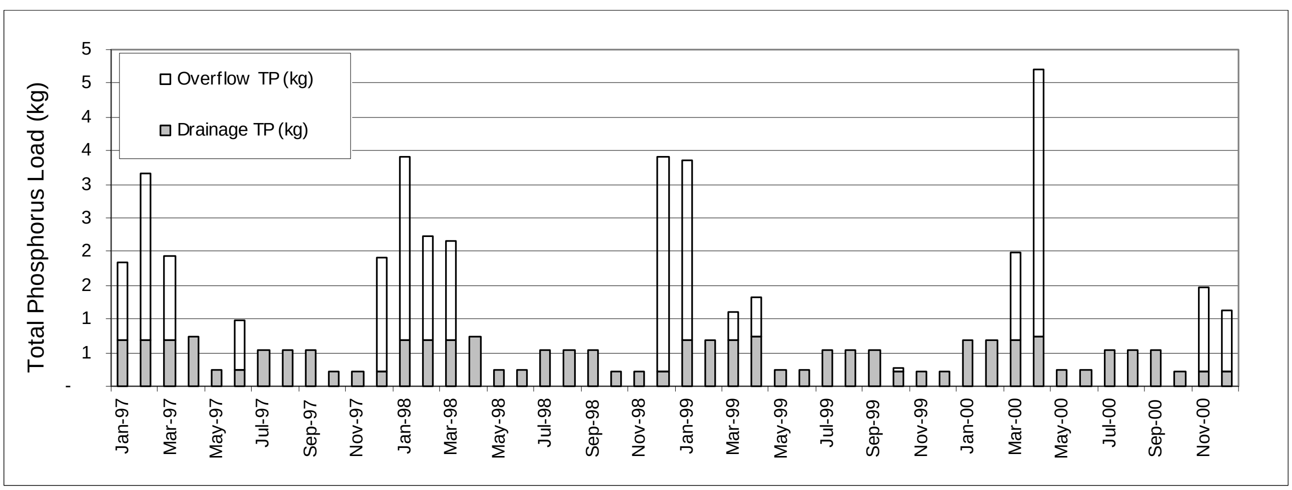


Figure A-10. Monthly Catfish Pond Overflow and Drainage Phosphorus Load

6.0 GWLF Model Results

The GWLF model was run for a 10-year period from April 1, 1990, to March 31, 1999. The first year of the model run was excluded because the GWLF model takes approximately 1 year to stabilize.

The predicted annual sediment, nitrogen, and phosphorus loads for April 1991 to March 1999 are shown in Figure A-11 to A-13. The peak load generally follows the annual precipitation pattern, with the highest sediment, nitrogen, and phosphorus loads occurring in 1991 and 1996.

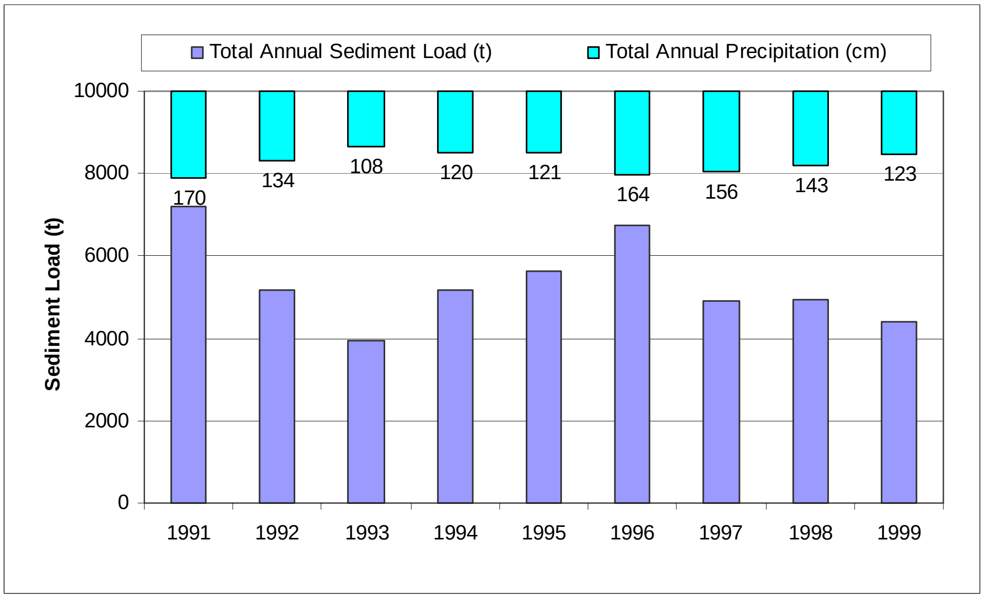


Figure A-11. Predicted Annual Sediment Load and Precipitation

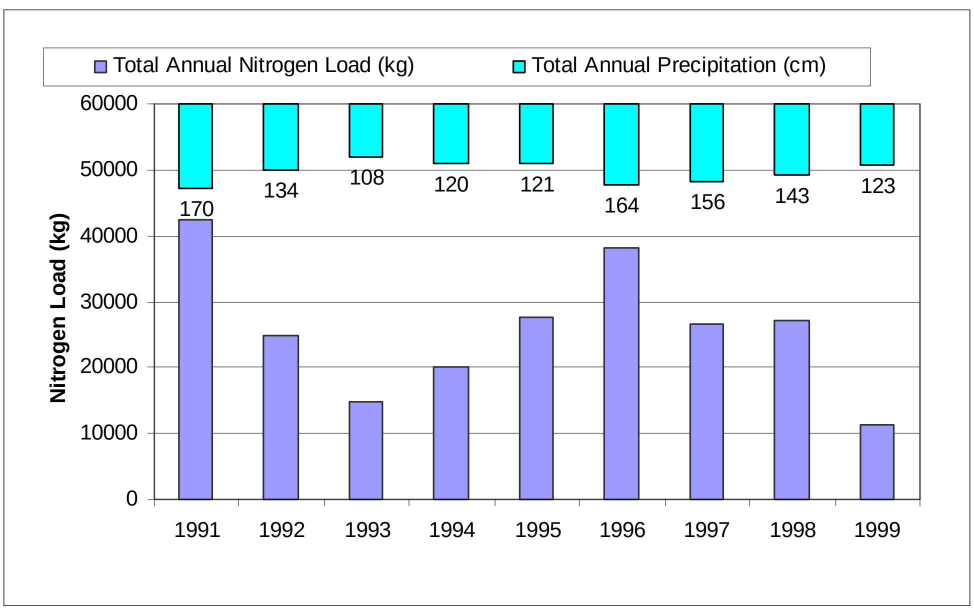


Figure A-12. Predicted Annual Nitrogen Load and Precipitation

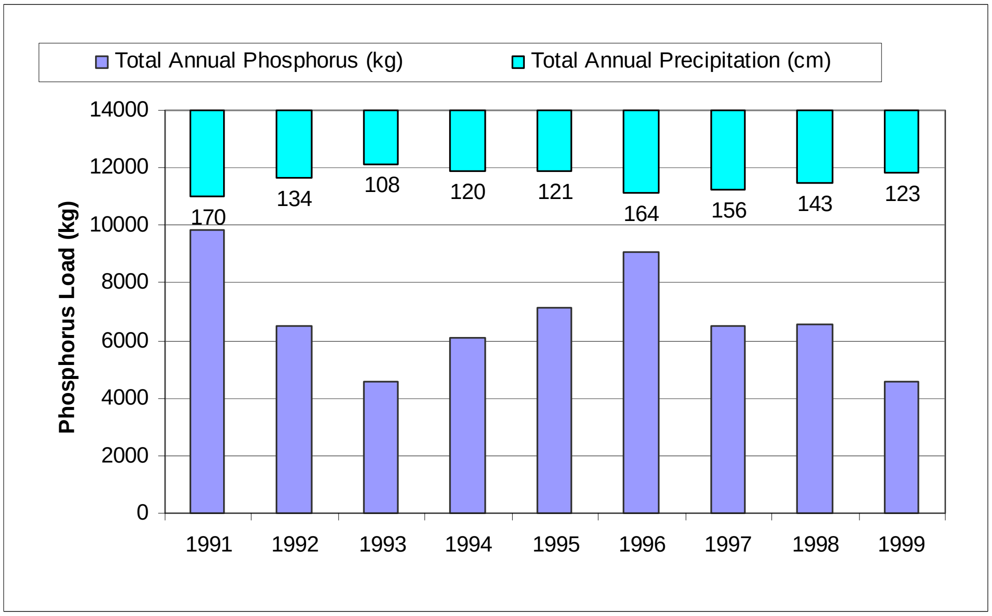


Figure A-13. Predicted Annual Phosphorus Load and Precipitation

The predicted average monthly sediment, nitrogen, and phosphorus loads are shown in Figures A-14 to A-16. These are the loads that actually reach the lake, and take into account the delivery ratio. The predicted load generally follows the monthly inflow pattern, with the highest sediment, nitrogen, and phosphorus loads occurring in winter and early spring.

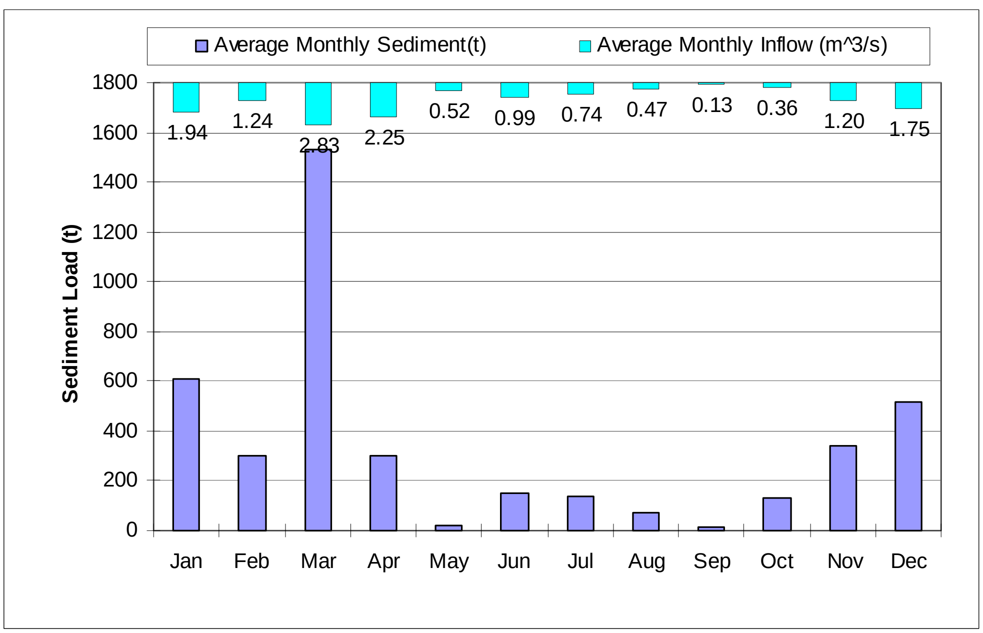


Figure A-14. Predicted Average Monthly Sediment Load and Inflow

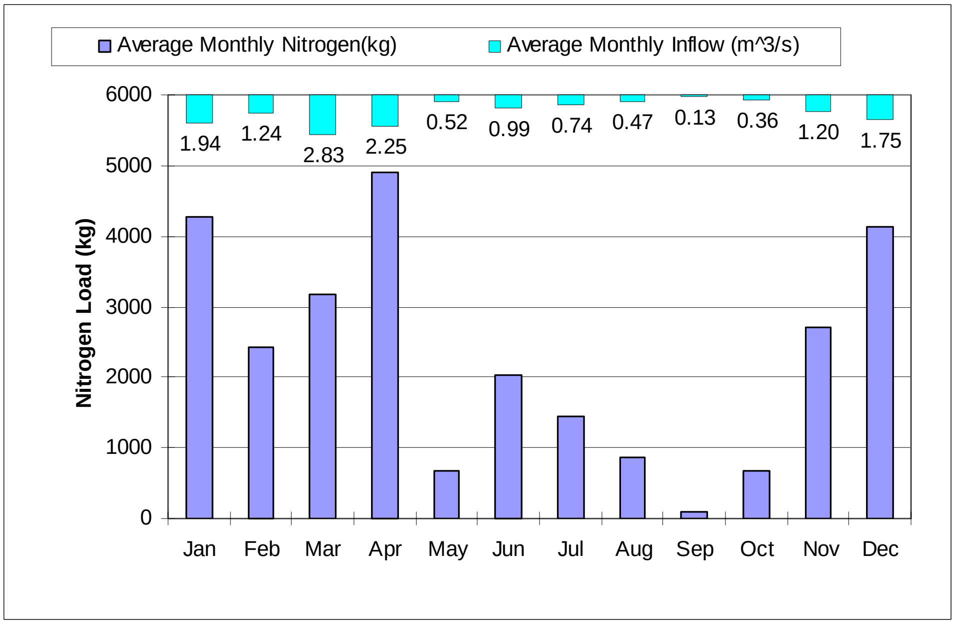


Figure A-15. Predicted Average Monthly Nitrogen Load and Inflow

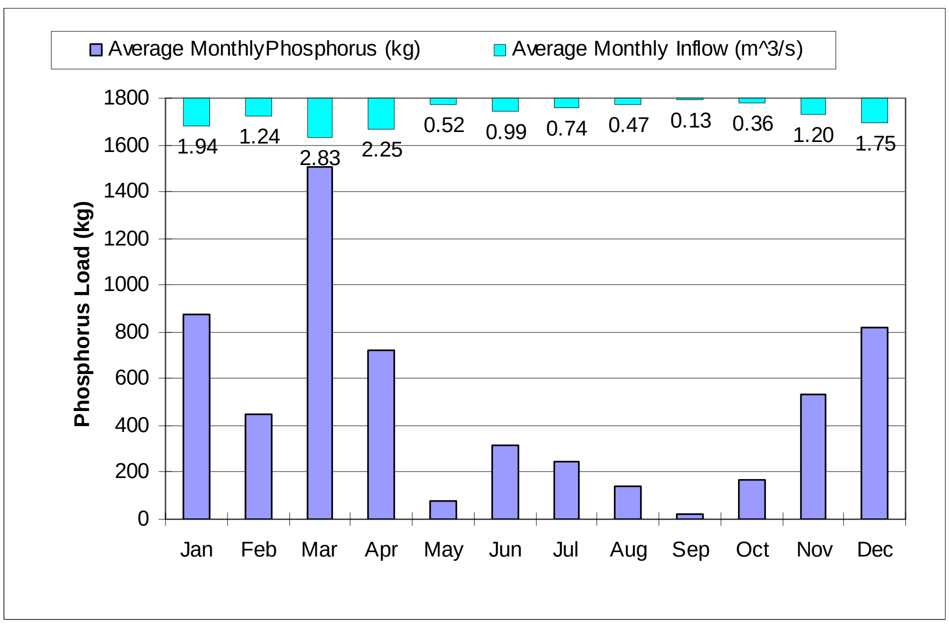


Figure A-16. Predicted Average Monthly Phosphorus Load and Inflow

7.0 Watershed Model Results

Sediment, total nitrogen, and total phosphorus loads by land use category are shown in Table A-4.

Table A-4: Predicted Average Annual Sediment, Nitrogen, and Phosphorus Loads

Land Use Category	Sediment Load (tons/year)	Total Nitrogen Load (tons/year)	Total Phosphorus Load (tons/year)
Cultivated Agriculture	4,770	21.39	5.70
Non Cultivated Agriculture	331	2.49	0.65
Catfish Ponds	2	0.55	0.01
Residential	28	0.42	0.06
Other	216	1.45	0.35
Total	5,347	26.29	6.77

7.1 Siltation Rate and Estimated Life Span

The siltation rate in Bee Lake was assessed using the mean annual sediment load and the estimated trap efficiency. In addition, this analysis relies on two fundamental assumptions:

- Sediment accumulation occurs homogeneously over the entire lake area.
- Lake life span extends until approximately 50 percent of the lake surface area or 30 percent of the lake volume is reached. At this point the lake in considered "non-functioning."

Trap efficiency refers to the ability of lakes and reservoirs to retain a portion of the sediment loading. This efficiency is expressed as the percent of sediment retained compared to the total incoming sediment. The Brune method (Chow, 1953) is a widely used trap efficiency estimation method based on the ratio of waterbody volume to the annual inflow volume.

$$E = 100 * 97^{0.19^{\log(C/I)}}$$

where

E =Trap Efficiency
C = Lake Capacity (Volume)
I = Inflow Volume

Based on this equation, the mean annual trap efficiency for Bee Lake is 96 percent. The predicted average sedimentation rate for the years 1991 to 1999 is 0.10 cm/year. The estimated life span based on the predicted sedimentation rate is 980 years.

7.2 Model Scenarios

The GWLF model was run for five additional scenarios to evaluate the effects of different land practices as well as the incorporation of wooded buffers. The goal of this analysis was to identify reasonable and achievable sedimentation rate targets while considering realistic land management and land use conversion options as well as long-term effects on the lake. However, the analysis does not attempt to include all the possible changes in land use and land management. Many other available options have not been included in this report. The selected scenarios are described in Table A-5. Table A-6 presents mean annual sediment load and the mean annual siltation rate for existing conditions and the additional scenarios.

Table A-5. Existing Condition and Model Scenarios

	Scenario	Description
Existing	Moderate Tillage	The C factor in the USLE equation was adjusted to reflect moderate tillage practices on cultivated agricultural land.
Scenarios	Conventional Tillage	The C factor in the USLE equation was adjusted to reflect conventional tillage practices on cultivated agricultural land.
	50% Wooded and Moderate Tillage	The C factor in the USLE equation was adjusted to reflect moderate tillage practices on cultivated agricultural land. The wooded area was increased from 20 percent to 50 percent and agricultural land was reduced from 66 percent to 43 percent of the watershed area.
	No Tillage	The C factor in the USLE equation was adjusted to reflect no tillage practices on cultivated agricultural land.
	50% Wooded and No Tillage	The C factor in the USLE equation was adjusted to reflect no tillage practices on cultivated agricultural land. The wooded area was increased from 20 percent to 50 percent and agricultural land was reduced from 66 percent to 43 percent of the watershed area.
	100% Wooded	The wooded area was increased from 20 percent to 100 percent of the watershed area.

Table A-6. 1991-1999 Mean Annual Sediment Load

Scenario	Sediment Load (kt)	Siltation Rate (cm/yr)
Conventional Tillage	8.58	0.17
Moderate Tillage (Baseline)	**5.35**	**0.10**
50% Wooded and Moderate Tillage	3.55	0.07
No Tillage	2.97	0.06
50% Wooded and No Tillage	2.15	0.04
100% Wooded	1.07	0.02

The siltation rates and estimated life spans for the existing conditions and additional scenarios are shown in Figures A-17 and A-18, respectively. The siltation rates and estimated life spans in this analysis are based on the conservative assumption that no compaction occurs in the deposited sediment and the specific weight of the sediment remains constant at 1 g/cm^3 (62 lbs/ft^3). It is expected that the actual siltation rates will be lower and estimated life span will be longer due to the compaction of the silt and clay factions of deposited sediment. Compaction occurs when sediment particles are slowly pressed together over time, reducing the pore space between them. Over extended periods compaction of silt and clay factions of sediment can increase the specific weight of the sediment and decrease the volume occupied by the sediment (Vanoni, 1975).

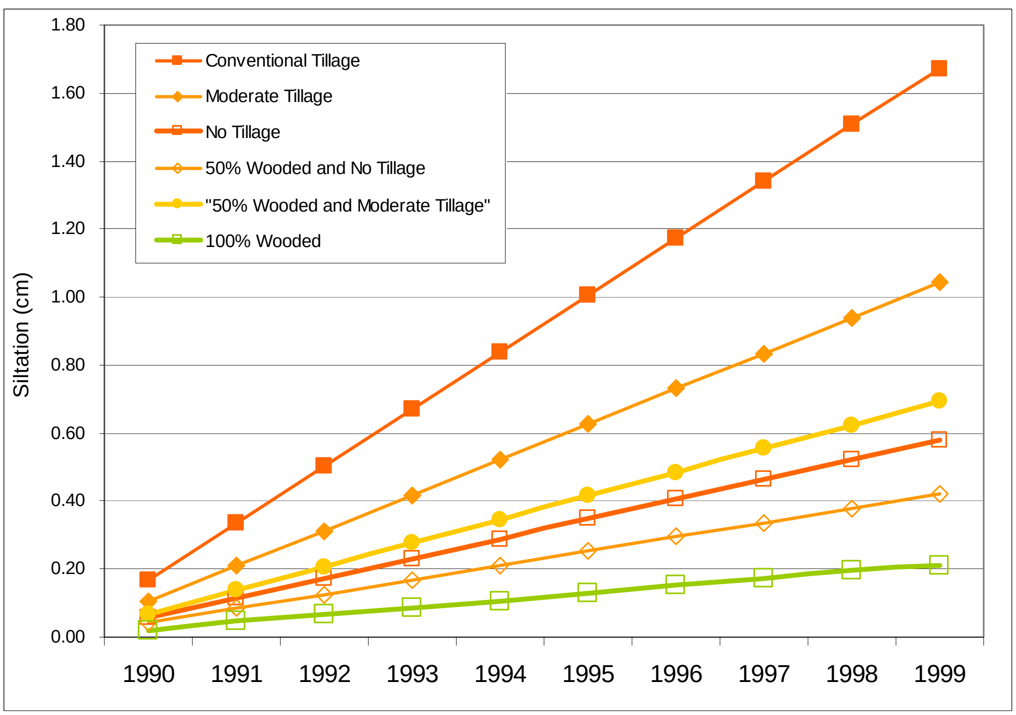


Figure A-17. In-Lake Siltation Existing Conditions and Modeling Scenarios

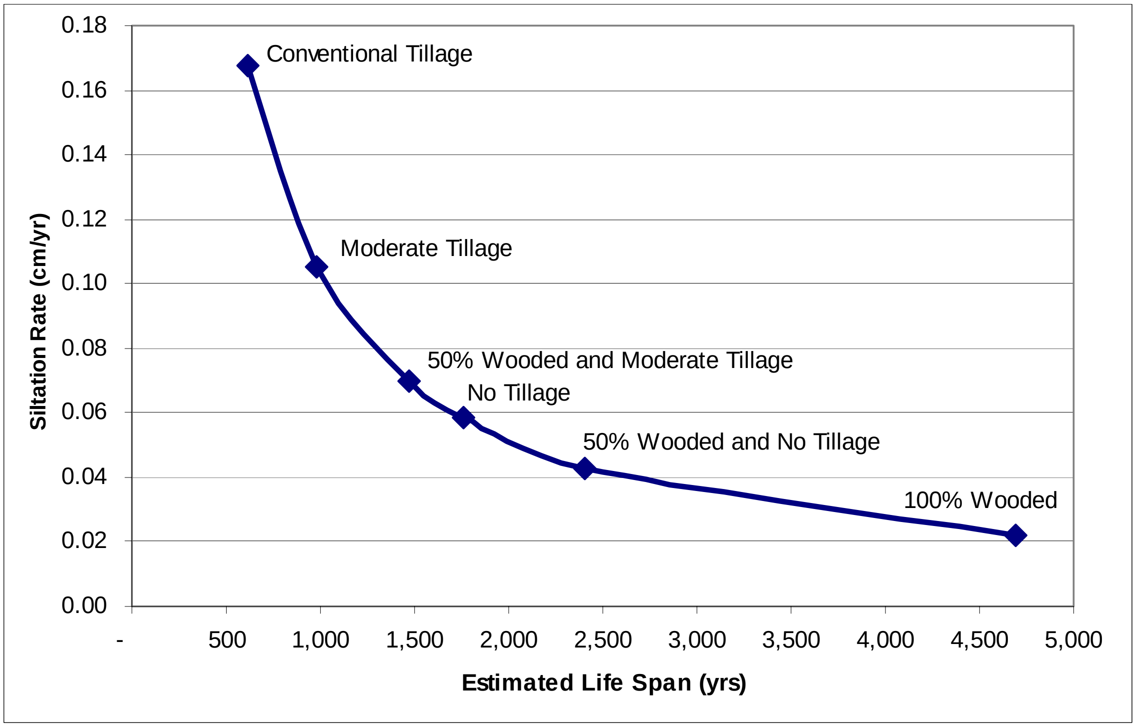


Figure A-18. Estimated Life span for Scenarios

After the results of each of these scenarios were reviewed, MDEQ determined that the TMDL should be based on a range of siltation rates, reflecting the land management practices that could reasonably be put in place in the Bee Lake watershed. The upper limit of the siltation rate was set to reflect the land management scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would continue to be cultivated using the moderate tillage practices that are currently in place. Thus, the upper limit of the siltation rate in Bee Lake is 0.07 cm/year. The lower limit of the siltation rate was set based on the most conservative land use management practices that would be practicable for the Bee Lake watershed. The most conservative practices were determined to be the scenario in which some of the agricultural land is returned to wooded areas, so that 50 percent of the total watershed is wooded. The remaining agricultural areas would be cultivated so that no tillage was done in the watershed. Thus, the lower limit of the siltation rate in Bee Lake is 0.04 cm/year.

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APPENDIX B

Bee Lake Water Quality Model

1.0 Development of the Water Quality Model for the Bee Lake

Bee Lake is a Yazoo river oxbow. It is fairly long (approximately 14.8 miles) and narrow (about 0.12 mile). Inlake conditions vary along the depth of the system, and vertical stratification occurs with the bottom layer becoming anoxic during summer. The current MDEQ water quality standard requires meeting daily average and daily minimum dissolved oxygen (DO) criteria, as no nutrient criteria currently exist. Because of these technical and regulatory considerations, the CE-QUAL-W2 hydrodynamic and water quality model (Cole and Buchak, 1995) was used to simulate eutrophication processes within the lake.

There were very little monitoring data available for Bee Lake that could be used to set up the kinetic parameters in the model. Because of this, kinetic parameters developed for another nearby lake, Wolf Lake near Lake City, were used to develop the Bee Lake model.

2.0 Model Framework

The U.S. Army Corps of Engineers CE-QUAL-W2 model was selected as the receiving water model for simulating the eutrophication processes in Bee Lake. CE-QUAL-W2 (W2) is a two-dimensional, longitudinal/vertical (laterally averaged), hydrodynamic and water quality model. The model allows application to multiple branches for geometrically complex waterbodies (dendritic/branching lakes and reservoirs) with variable grid spacing, time-variable boundary conditions, and multiple inflows and outflows from point/nonpoint sources and precipitation.

The two major components of the W2 model are hydrodynamics and water quality kinetics. Both of these components are coupled, that is the hydrodynamic output is used to drive the water quality at every time step. The hydrodynamic portion of the model predicts water surface elevations, velocities, and temperature. The water quality portion can simulate 21 constituents including DO, nutrients, and phytoplankton interactions. Any combination of constituents can be simulated. Refer to document *CE-QUAL-W2: A Two-Dimensional Laterally Averaged, Hydrodynamic and Water Quality Model, Version 2.0–Users Manual (EL-95)* for a more detailed discussion of simulated processes and model parameters.

3.0 Model Configuration

Model configuration involved setting up the model computational grid (bathymetry) and setting initial conditions, boundary conditions, and hydraulic and kinetic parameters for the hydrodynamic and water quality simulations. This section describes the configuration and key components of the model.

3.1 Segmentation/Computational Grid Setup

The computational grid setup defines the process of representing Bee Lake in the finite difference scheme. Bee Lake consists of a single main branch, which represents its circuitous shape (Figure B-1). The model requires the user to set up the bathymetry file for the branch defining the upstream and downstream segment. Bathometric information for the lake was available from a map provided by the Mississippi State Game and Fisheries Commission. The model was set up with a constant width and depth along each segment. The surface widths for each segment were derived from U.S. Geological Survey (USGS) quad maps. The model was configured with 18 longitudinal segments, each with lengths ranging from 500 to 1,500 meters long, and contains up to a maximum of three 1-meter thick vertical layers.

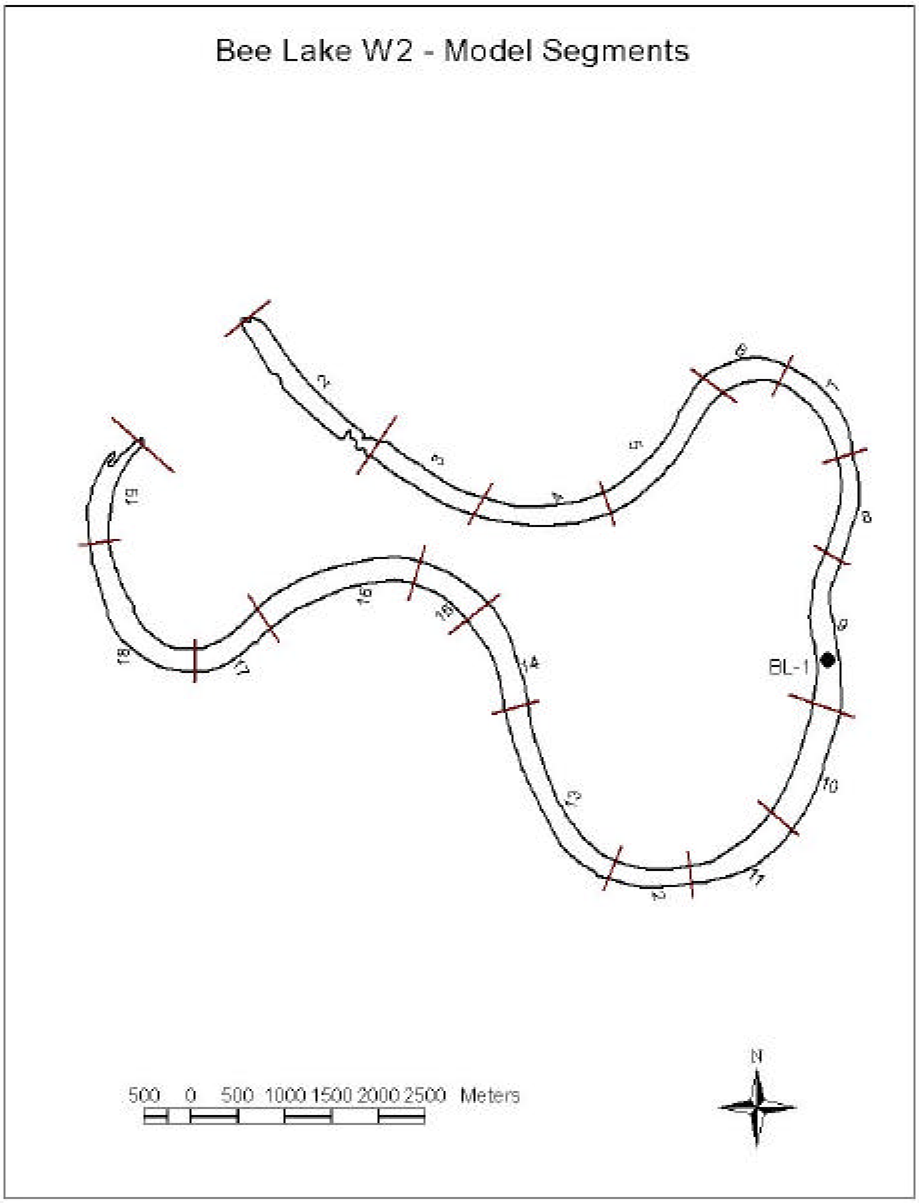

Figure B-1. Bee Lake Segmentation

3.2 Initial Conditions

The W2 model requires specifying initial conditions in the control and bathymetry input files. The control file specifies the initial temperature and constituents (ammonia, nitrate-nitrite, organic nitrogen, ortho-phosphorus, and organic phosphorus). A constant initial temperature of 16 °C and default constant constituents were specified for the lake along the entire length and depth. All the initial conditions values were based data from the one time monitoring done in the lake during 1994 and 1995 (MDEQ, 1994 and 1995) at location BL-1 (Figure B-1), as well as from the model developed for Wolf Lake. The number and location of inflow/outflows are also provided in the control file as part of the initial conditions. For Bee Lake, inflows were specified at segments 2 and outflow at segment 19. In addition to the geometric data in the bathymetry file, an initial water surface elevation was specified for the bathymetry of the lake (set equal to the deepest point in the lake).

3.3 Boundary Conditions/Linkages

Boundary conditions are a set of input files required to drive the W2 model. They represent external contributions to the lake. For the inflows at Branch 1, a flow, concentration, and temperature input file was set up.

The hydrodynamic component of the W2 model, including temperature predictions, was forced by monthly averaged inflows from the GWLF model and hourly surface airways meteorological data. The lake level was assumed to remain constant with the monthly average outflows set equal to inflows. The monthly average inflow rates used in the model for the period of simulation are shown in Table B-1. Because of the nature of the watershed, the majority of the loads were applied along the main branch as a nonpoint source load, which is distributed equally along each segment based on segment length. A small fraction of the load was provided as inflow.

Table B-1. Monthly Average Inflows and Total Nutrient Loads Estimated from the GWLF Model

Month	Monthly Average Inflow (m^3/sec)	Total Nitrogen (tons)	Total Phosphorus (tons)
1/1/1997	1.211	7.84	1.77
2/1/1997	1.715	8.86	1.73
3/1/1997	1.196	3.56	1.65
4/1/1997	0.714	3.46	0.39
5/1/1997	0.142	0.39	0.04
6/1/1997	0.949	5.02	0.77
7/1/1997	0.131	0.44	0.06
8/1/1997	0.160	0.52	0.07
9/1/1997	0.030	0.01	0.00
10/1/1997	0.084	0.07	0.01
11/1/1997	0.407	2.18	0.43
12/1/1997	0.691	4.31	0.91
1/1/1998	1.106	5.81	1.02
2/1/1998	0.916	3.55	0.52
3/1/1998	0.939	3.13	1.46
4/1/1998	0.082	0.06	0.00
5/1/1998	0.332	1.74	0.21
6/1/1998	0.054	0.02	0.00
7/1/1998	0.238	0.72	0.09
8/1/1998	0.042	0.02	0.00
9/1/1998	0.097	0.27	0.03
10/1/1998	0.032	0.02	0.00
11/1/1998	0.338	1.46	0.19
12/1/1998	2.066	13.44	2.58
1/1/1999	1.331	7.52	1.48
2/1/1999	0.027	0.03	0.00
3/1/1999	1.122	2.88	1.13
4/1/1999	0.380	1.37	0.14
5/1/1999	0.269	0.46	0.04
6/1/1999	0.423	1.97	0.35
7/1/1999	0.283	1.26	0.30
8/1/1999	0.010	0.01	0.00
9/1/1999	0.085	0.25	0.05
10/1/1999	0.275	1.74	0.57
11/1/1999	0.043	0.09	0.02
12/1/1999	0.091	0.16	0.05
1/1/2000	0.108	0.36	0.08
2/1/2000	0.039	0.04	0.01
3/1/2000	1.172	3.92	2.21
4/1/2000	2.897	17.45	2.79
5/1/2000	0.089	0.02	0.00
6/1/2000	0.079	0.02	0.00
7/1/2000	0.010	0.01	0.00
8/1/2000	0.040	0.01	0.00
9/1/2000	0.010	0.01	0.00

Month	Monthly Average Inflow (m^3/sec)	Total Nitrogen (tons)	Total Phosphorus (tons)
10/1/2000	0.010	0.02	0.00
11/1/2000	1.591	9.90	2.02
12/1/2000	0.358	1.85	0.28

Temperature time series data corresponding to each inflow for the main branch of the lake were required. The watershed model does not simulate temperature, and no monitoring data exist for the lake. A generalized temperature time series was created based on the nearby Wolf Lake temperature monitoring data. The observed temperature data followed a sinusoidal pattern along the year for all the monitored temperature stations at Wolf Lake and its inlet. These monitoring data were fitted with a sine curve to obtain a generalized temperature time series that was used for all simulated years and distributed tributary boundary conditions in the Bee Lake watershed. The sine function equation is given as

$$T(t) = avgT + Amp \cdot \sin(\Omega \cdot t - f)$$

where

avgT	= average temperature for the time period (J)
Amp	= amplitude
S	= 2B/J
f	= horizontal shift
t	= temperature in deg C

Parameters in the sine curve equation (amplitude and horizontal phase shift) were adjusted until the line of equal value was reached. Figure B-2 shows the fitted temperature for the temperature data (Wolf Lake inlet data) and the regression of calculated versus observed temperature.

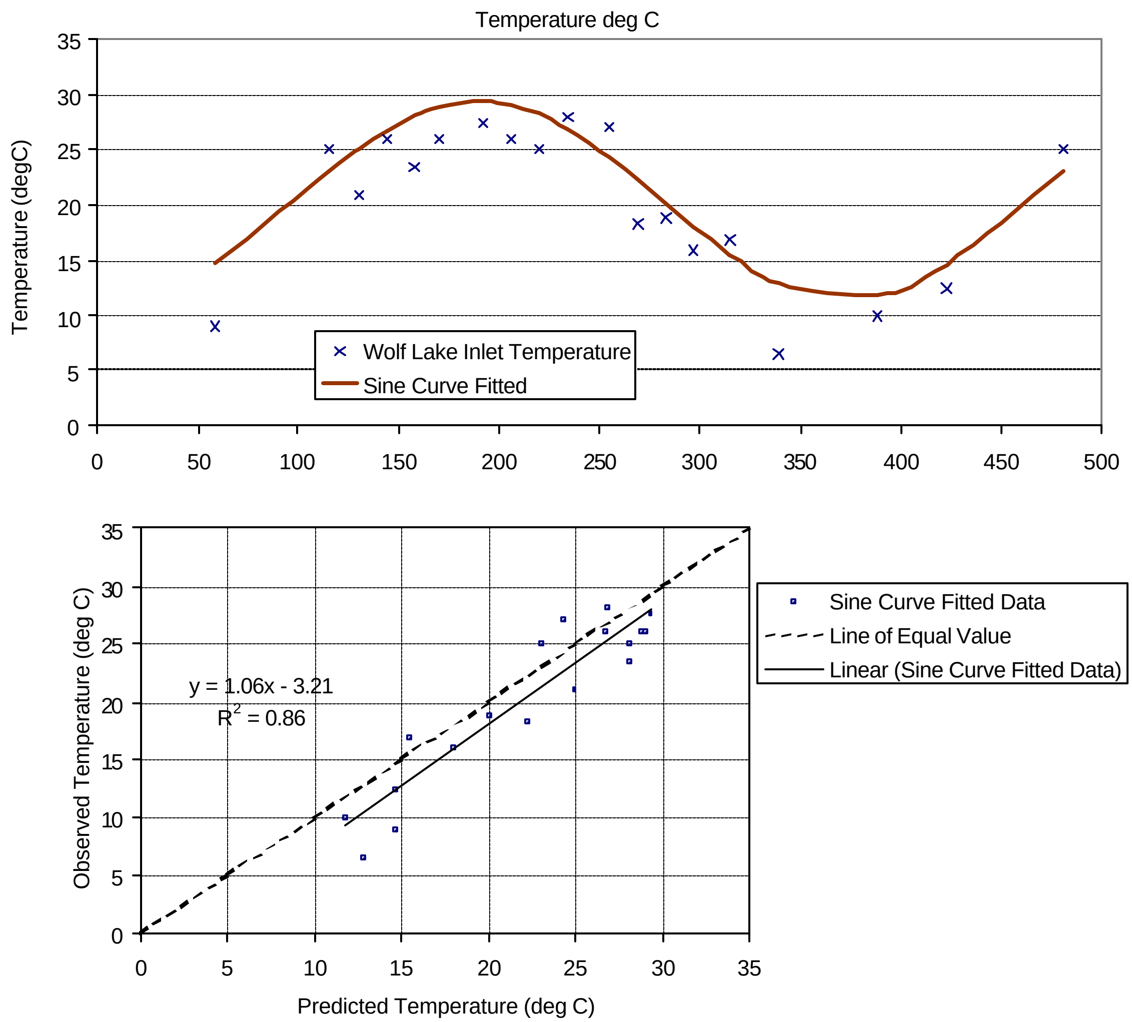

Figure B-2. Sine Curve Fitted Temperature Data Using Wolf Lake Inlet Monitoring Data.

The water quality component of the W2 model requires loading of dissolved and particulate organic material, ammonia, nitrate-nitrite, ortho-phosphorus and DO. These loadings were estimated from the total load estimates from the GWLF model (Table B-1). Nutrient ratios as determined from inlake monitoring data for Wolf Lake were used to partition total nitrogen and total phosphorus into ammonia, nitrate-nitrite, organic nitrogen, ortho-phosphorus, and organic phosphorus. Table B-2 shows the time-averaged ratios from the Wolf Lake study that were used. Dissolved organic material (DOM) loadings were estimated based on one-half of the organic nitrogen load. Particulate organic material (POM) loadings were estimated from the remaining half of the organic nitrogen and the total organic phosphorus (Tetra Tech, 1997). The DOM and POM form the source of carbon for the model.

Table B-2. Time Averaged Nutrient Ratios (estimated from the inlake data of Wolf Lake)

Station	Segment	NH_3/TN	NOx/TN	Organic N/TN	Ortho-P/TP	Organic P/TP
Average	9	0.1232	0.1762	0.7006	0.3824	0.6176

The DO was assumed to be entering that lake at 90 percent of saturation. The saturation value was derived from the *Rates Kinetics and Constants Handbook* (EPA, 1985). A value of 6.67 mg/L of DO was ultimately used.

3.4 Meteorological Data

Meteorological data are an important component of the W2 model. The surface boundary conditions are determined by the meteorological conditions. The meteorological data required by the W2 model are air temperature, dewpoint temperature, wind speed, wind direction, and cloud cover. In general, hourly data are recommended (expressed in Julian Day) (Cole and Buchak, 1995). Hourly meteorological data from the Jackson Airport, Mississippi, which was the nearest available hourly monitoring station and had the most complete dataset, were used (Figure B-3). Short-wave solar radiation is directly calculated in the W2 model using cloud cover. Evaporation is calculated by the model from air temperature, dewpoint temperature, and wind speed.

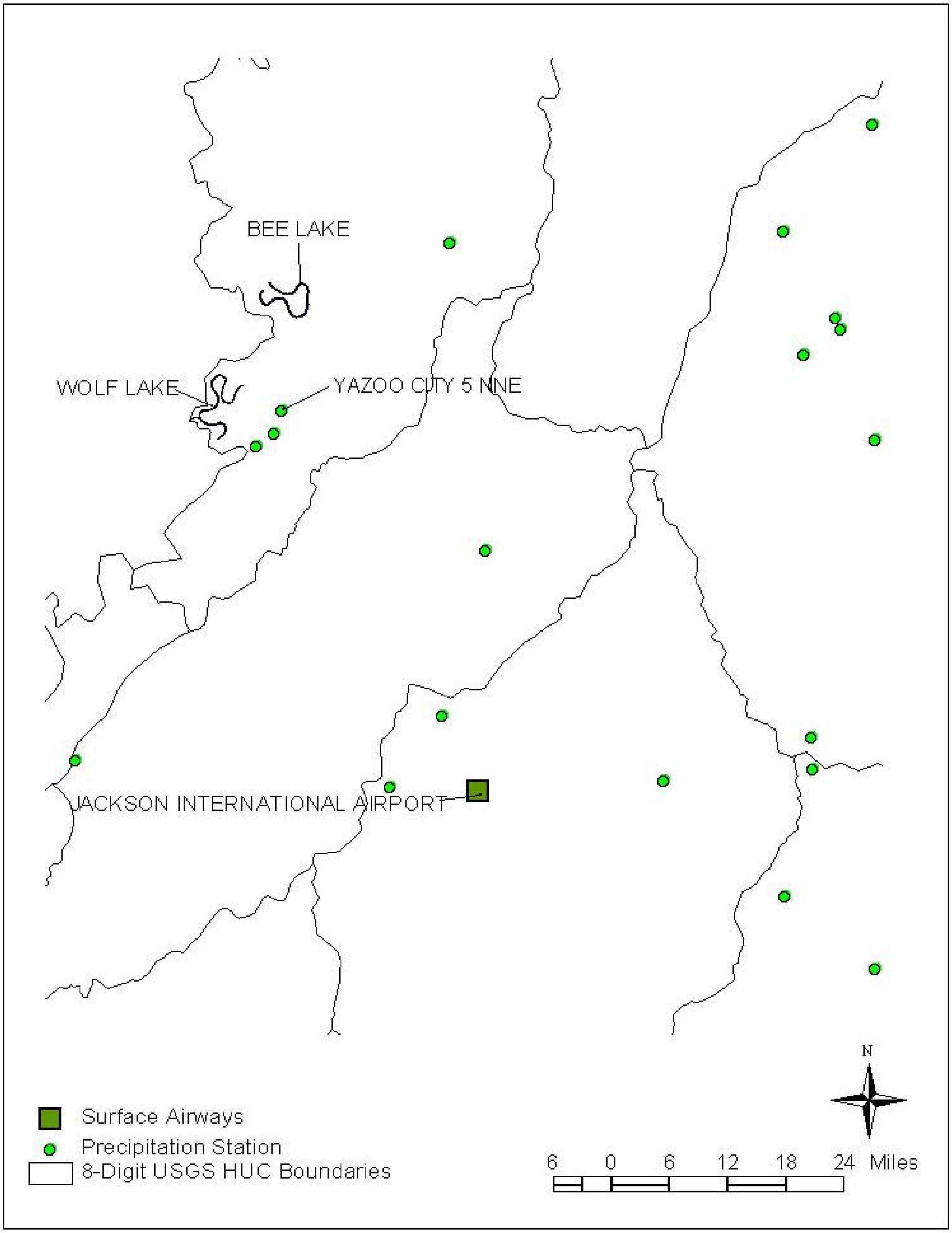

Figure B-3. Weather Station Locations

Recent precipitation data from Yazoo City (Figure B-3) were also available, but for the lake model, evaporation was assumed to cancel out precipitation had any major influence. However, it can be noted that the effects of precipitation were indirectly considered via the loads coming from the watershed model for which precipitation was the major driver. The GWLF model used the Yazoo City rain gage, which had the most complete and recent precipitation data (Figure B-3).

For the critical condition period chosen (between 1997 and 2000) hourly climatological data (unedited) exist on the National Oceanic and Atmospheric Administration (NOAA) National Data Center Web site (from July 1996 onward) for the Jackson Airport meteorological station. Hourly surface airways data were downloaded for each month, and a composite file was generated for this period.

3.5 Time Period

No monitoring data are available to support model calibration or validation. The only data are at location BE-1 (Figure B-1) for 1994 and 1995, which has DO and temperature profile measurements and some nutrient (total phosphorus, ammonia and nitrate nitrite) data. However, only one measurement was taken (in July) during each of these years. The time period chosen for model simulation was from 1997 to 2000. As shown in Figure B-4, 1997 to 2000 exhibited a wide range of hydrologic conditions with wet and dry periods. Lakes are also typically conducive to eutrophication under these conditions.

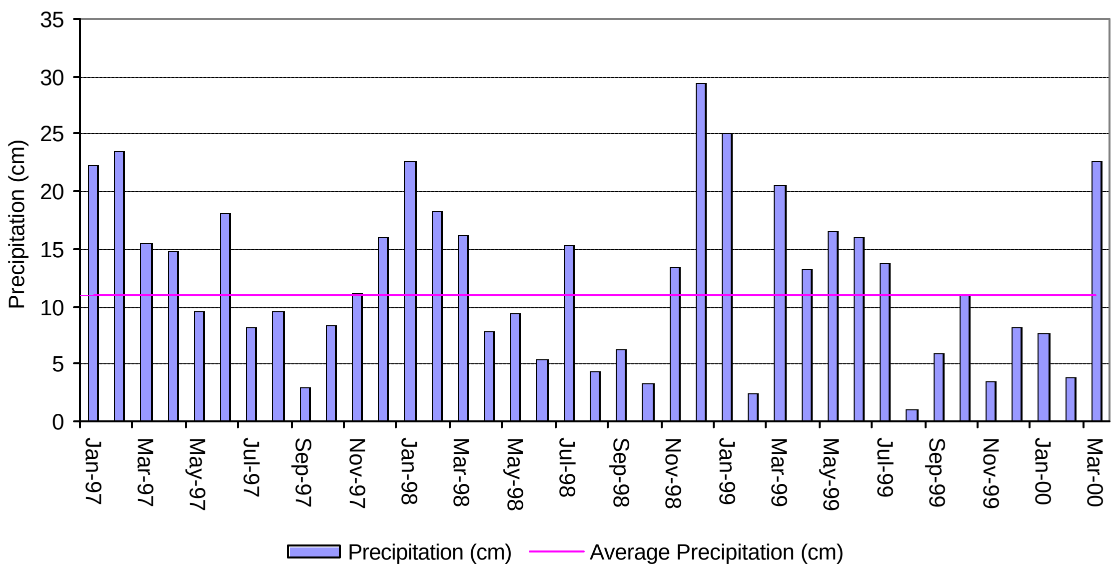

Figure B-4. Monthly Precipitation for Critical Period Used for Simulation 1997 to 2000 (Yazoo City)

The year 1997 was a predominantly wet year, with an annual rainfall average of approximately 160 cm (above the mean annual average of 130 cm), this compares with 1999, which was an average year, and 2000, which was a relatively dry year with an annual average of 105 cm (below the mean annual average of 130 cm) (Figure B-5). The years 1994 and 1995 were average years (Figure B-5) and were not chosen for simulation since a complete data set of meteorological data could not be obtained. The years 1997 to 2000 had a complete meteorological dataset.

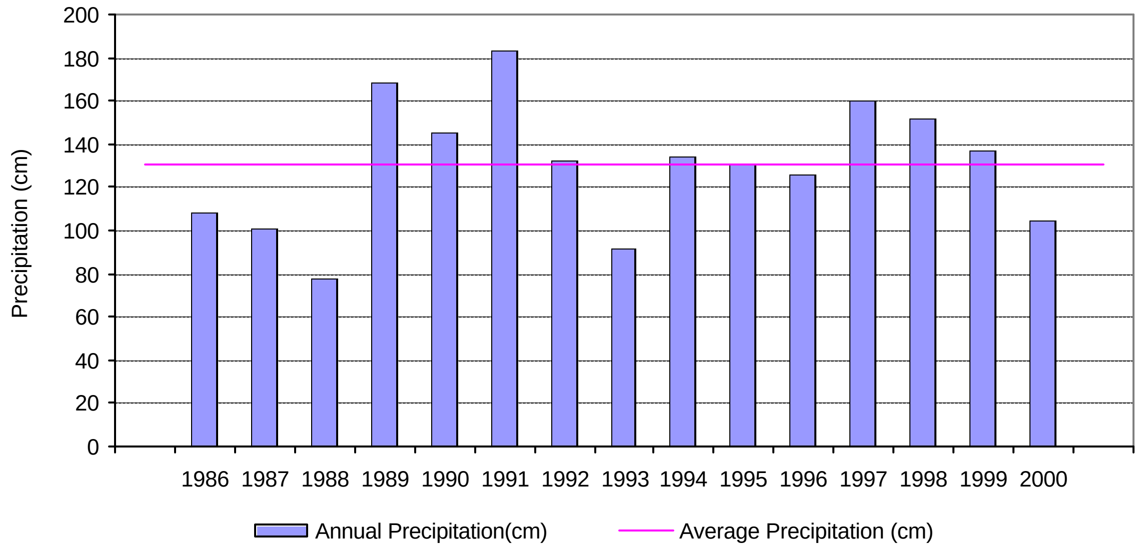

Figure B-5. Monthly Precipitation (Yazoo City)

4.0 Modeling Parameters

Coefficients are needed to describe the water quality reaction rates in the lake. No monitoring data exist within Bee Lake to calibrate the kinetics for the lake. The modeling parameters from the Wolf Lake W2 modeling study were applied to Bee Lake. Since Bee Lake is in the same vicinity as Wolf Lake, it is assumed that the kinetic parameters of Bee Lake would be similar to those of Wolf Lake. The water quality calibration coefficients, as well as the phytoplankton coefficient data (from the Wolf Lake model) used in this study, are presented in Table B-3.

Table B-3. Kinetic Coefficients used in the Bee Lake Model

Parameter	Description	Units	Value
PO4R	Sediment release rate of phosphorus	fraction of SOD	0.015
PARTP	Phosphorus partitioning coefficient for suspended solids	-	0.6
NO3DK	Nitrate decay rate	day^{-1}	0.102
NO3T1	Lower temperature for nitrate decay	^{o}C	0
NO3T2	Upper temperature for nitrate decay	^{o}C	20
NO3K1	Lower temperature rate multiplier for nitrate decay	-	0.2
NO3K2	Upper temperature rate multiplier for nitrate decay	-	0.99
NH4DK	Ammonium decay rate	day^{-1}	0.30
NH4R	Sediment release rate of ammonium	fraction of SOD	0.05
NH4T1	Lower temperature for ammonium decay	^{o}C	0
NH4T2	Upper temperature for ammonium decay	^{o}C	20
NH4K1	Lower temperature rate multiplier for ammonium decay	-	0.2
NH4K2	Upper temperature rate multiplier for ammonium decay	-	0.99
SOD	Sediment Oxygen Demand	$gCm^{2}day^{-1}$	0.5
AG	Growth rate	day^{-1}	2.5
AR	Dark respiration rate	day^{-1}	0.08
AE	Excretion rate	day^{-1}	0.04
AM	Mortality rate	day^{-1}	0.05
AS	Settling rate	day^{-1}	0.1
AHSP	Phosphorus half-saturation coefficient	$g.m^{-3}$	0.003
AHSN	Nitrogen half-saturation coefficient	$g.m^{-3}$	0.014
ASAT	Light saturation	$W.m^{-3}$	100
AT1	Lower temperature for minimum algal rates	^{o}C	5
AT2	Lower temperature for maximum algal rates	^{o}C	25
AT3	Upper temperature for minimum algal rates	^{o}C	30
AT4	Upper temperature for maximum algal rates	^{o}C	33
AK1	Lower temperature rate multiplier for minimum algal rates	-	0.1
AK2	Lower temperature rate multiplier for maximum algal rates	-	0.85
AK3	Upper temperature rate multiplier for minimum algal rates	-	0.85
AK4	Upper temperature rate multiplier for maximum algal rates	-	0.1

5.0 Assumptions and Limitations

The assumptions and limitations used are as follows:

- The kinetic parameters of Wolf Lake were assumed to be applicable to Bee Lake.
- The monthly loads are assumed to sufficiently represent loading variability to the lake model.
- Since a complete hourly dataset for the meteorological data was not available, the model uses representative rather than actual wind data in determining hydrodynamic transport and surface reaeration.
- The model does not explicitly predict sediment diagenesis processes and the long-term effects of reduced nutrient loadings.

- The watershed model gives an estimate of the total phosphorus and total nitrogen. These loadings were split based on the nutrient ratios determined from inlake monitoring data to provide the required loadings (as per W2 model requirements) of dissolved and particulate organic material, ammonia, nitrate-nitrite, and ortho-phosphorus that feed into the W2 model. The ratios derived from monitoring in Wolf Lake were assumed to be applicable to this study.

6.0 Model Calibration

Although monitoring data exists for the years 1994 and 1995 (one day in each year), no model calibration could be performed because of insufficient inlake monitoring data. There is no complete meteorological data set for the years 1994 and 1995 and they were normal years in terms of precipitation (Figure B-5). The period from 1997 to 2000 was chosen for model simulation. The year 1999 is similar to 1994 and 1995 in terms of annual precipitation totals and a complete meteorological data set was available. The DO simulation results for the years 1997–2000 at station BL-1 segment 9 are presented below (Figure B-6).

Figure B-6. DO Simulation Results (1997-2000)

7.0 References

Cole, T.M., and E.M. Buchak. 1995. CE-QUAL-W2: *A Two-Dimensional Laterally Averaged, Hydrodynamic And Water Quality Model, Version 2.0.* Instructional Report EL-95-draft. U.S. Army Corps of Engineers, Waterway Experiment Station, Vicksburg, MS.

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